FOR THE INCREASE AND DIFFUSION OF KNOWLEDGE AMONG MEN

PER ORBEM

SMITHSONIAN INSTITUTION

WASHINGTON 1846

ANNUAL REPORT OF THE BOARD OF REGENTS OF

THE SMITHSONIAN INSTITUTION

SHOWING THE

OPERATIONS, EXPENDITURES, AND CONDITION OF THE INSTITUTION FOR THE YEAR ENDED JUNE 30

1938

(Publication 3491)

UNITED STATES
GOVERNMENT PRINTING OFFICE
WASHINGTON : 1939

For sale by the Superintendent of Documents, Washington, D. C. - - - - - - - Price $1.50 (cloth cover)

LETTER OF TRANSMITTAL

Smithsonian Institution,
Washington, December 9, 1938.

To the Congress of the United States:

In accordance with section 5593 of the Revised Statutes of the United States, I have the honor, in behalf of the Board of Regents, to submit to Congress the annual report of the operations, expenditures, and condition of the Smithsonian Institution for the year ended June 30, 1938. I have the honor to be,

Very respectfully, your obedient servant,

C. G. Abbot, *Secretary*.

CONTENTS

GENERAL APPENDIX

LIST OF PLATES

THE SMITHSONIAN INSTITUTION

June 30, 1938

Presiding officer ex officio.—Franklin D. Roosevelt, President of the United States.

Chancellor.—Charles Evans Hughes, Chief Justice of the United States.

Members of the Institution:

Franklin D. Roosevelt, President of the United States.
John N. Garner, Vice President of the United States.
Charles Evans Hughes, Chief Justice of the United States.
Cordell Hull, Secretary of State.
Henry Morgenthau, Jr., Secretary of the Treasury.
Henry Hines Woodring, Secretary of War.
Homer S. Cummings, Attorney General.
James A. Farley, Postmaster General.
Claude A. Swanson, Secretary of the Navy.
Harold L. Ickes, Secretary of the Interior.
Henry A. Wallace, Secretary of Agriculture.
Daniel C. Roper, Secretary of Commerce.
Frances Perkins, Secretary of Labor.

Regents of the Institution:

Charles Evans Hughes, Chief Justice of the United States, Chancellor.
John N. Garner, Vice President of the United States.
M. M. Logan, Member of the Senate.
Charles L. McNary, Member of the Senate.
Alben W. Barkley, Member of the Senate.
T. Alan Goldsborough, Member of the House of Representatives.
Charles L. Gifford, Member of the House of Representatives.
Clarence Cannon, Member of the House of Representatives.
Frederic A. Delano, citizen of Washington, D. C.
John C. Merriam, citizen of Washington, D. C.
R. Walton Moore, citizen of Virginia.
Roland S. Morris, citizen of Pennsylvania.
Harvey N. Davis, citizen of New Jersey.
Arthur H. Compton, citizen of Illinois.

Executive committee.—Frederic A. Delano, John C. Merriam, R. Walton Moore.

Secretary.—Charles G. Abbot.

Assistant Secretary.—Alexander Wetmore.

Administrative assistant to the Secretary.—Harry W. Dorsey.

Treasurer.—Nicholas W. Dorsey.

Editor.—Webster P. True.

Librarian.—William L. Corbin.

Personnel officer.—Helen A. Olmsted.

Property clerk.—James H. Hill.

UNITED STATES NATIONAL MUSEUM

Keeper ex officio.—Charles G. Abbot.

Assistant Secretary (in charge).—Alexander Wetmore.

Associate director.—John E. Graf.

SCIENTIFIC STAFF

Department of Anthropology:

Frank M. Setzler, head curator; W. H. Egberts, chief preparator.

Division of Ethnology: H. W. Krieger, curator; H. B. Collins, Jr., associate curator; Arthur P. Rice, collaborator.

Section of Musical Instruments: Hugo Worch, custodian.

Section of Ceramics: Samuel W. Woodhouse, collaborator.

Division of Archeology: Neil M. Judd, curator; Waldo R. Wedel, assistant curator; R. G. Paine, aid; J. Townsend Russell, honorary assistant curator of Old World archeology.

Division of Physical Anthropology: Aleš Hrdlička, curator; T. Dale Stewart, assistant curator.

Collaborators in anthropology: George Grant MacCurdy; D. I. Bushnell, Jr.

Associate in historic archeology: Cyrus Adler.

Department of Biology:

Leonhard Stejneger, head curator; W. L. Brown, chief taxidermist.

Division of Mammals: Gerrit S. Miller, Jr., curator; Remington Kellogg, assistant curator; H. Harold Shamel, senior scientific aid; A. Brazier Howell, collaborator.

Division of Birds: Herbert Friedmann, curator; J. H. Riley, associate curator; Alexander Wetmore, custodian of alcoholic and skeleton collections; Casey A. Wood, collaborator; Arthur C. Bent, collaborator.

Division of Reptiles and Batrachians: Leonhard Stejneger, curator; Doris M. Cochran, assistant curator.

Division of Fishes: Leonard P. Schultz, curator; E. D. Reid, aid.

Division of Insects: L. O. Howard, honorary curator; Edward A. Chapin, curator; William Schaus, honorary assistant curator; B. Preston Clark, collaborator.

Section of Hymenoptera: S. A. Rohwer, custodian; W. M. Mann, assistant custodian; Robert A. Cushman, assistant custodian.

Section of Myriapoda: O. F. Cook, custodian.

Section of Diptera: Charles T. Greene, assistant custodian.

Section of Coleoptera: L. L. Buchanan, specialist for Casey collection.

Section of Lepidoptera: J. T. Barnes, collaborator.

Section of Hemiptera: W. L. McAtee, acting custodian.

Section of Forest Tree Beetles: A. D. Hopkins, custodian.

Division of Marine Invertebrates: Waldo L. Schmitt, curator; C. R. Shoemaker, assistant curator; James O. Maloney, aid; Mrs. Harriet Richardson Searle, collaborator; Max M. Ellis, collaborator; Maynard M. Metcalf, collaborator; J. Percy Moore, collaborator; Joseph A. Cushman, collaborator in Foraminifera; Charles Branch Wilson, collaborator in Copepoda.

Division of Mollusks: Paul Bartsch, curator; Harald A. Rehder, assistant curator; Joseph P. E. Morrison, senior scientific aid; Mary Breen, collaborator.

Division of Echinoderms: Austin H. Clark, curator.

Division of Plants (National Herbarium): W. R. Maxon, curator; Ellsworth P. Killip, associate curator; Emery C. Leonard, assistant curator; Conrad V. Morton, aid; Egbert H. Walker, aid; John A. Stevenson, custodian of C. G. Lloyd mycological collection.

Section of Grasses: Agnes Chase, custodian.

Section of Cryptogamic Collections: O. F. Cook, assistant curator.

Section of Higher Algae: W. T. Swingle, custodian.
Section of Lower Fungi: D. G. Fairchild, custodian.
Section of Diatoms: Paul S. Conger, custodian.
Associates in Zoology: C. Hart Merriam, Mary J. Rathbun, C. W. Stiles, Theodore S. Palmer, William B. Marshall.
Associate Curator in Zoology: Hugh M. Smith.
Associate in Marine Sediments: T. Wayland Vaughan.
Collaborator in Zoology: Robert Sterling Clark.
Collaborators in Biology: A. K. Fisher, David C. Graham.

DEPARTMENT OF GEOLOGY:
R. S. Bassler, head curator; Jessie G. Beach, aid.
Division of Physical and Chemical Geology (systematic and applied): W. F. Foshag, curator; Edward P. Henderson, assistant curator; Bertel O. Reberholt, senior scientific aid.
Division of Mineralogy and Petrology: W. F. Foshag, curator; Frank L. Hess, custodian of rare metals and rare earths.
Division of Stratigraphic Paleontology: Charles E. Resser, curator; Gustav A. Cooper, assistant curator; Margaret W. Moodey, aid for Springer collection.
Section of Invertebrate Paleontology: T. W. Stanton, custodian of Mesozoic collection; Paul Bartsch, curator of Cenozoic collection.
Division of Vertebrate Paleontology: Charles W. Gilmore, curator; C. Lewis Gazin, assistant curator: Norman H. Boss, chief preparator.
Associate in Mineralogy: W. T. Schaller.
Associate in Paleontology: E. O. Ulrich.
Associate in Petrology: Whitman Cross.

DEPARTMENT OF ARTS AND INDUSTRIES:
Carl W. Mitman, head curator.
Division of Engineering: Frank A. Taylor, curator.
Section of Mechanical Technology: Frank A. Taylor, in charge; Fred C. Reed, scientific aid.
Section of Aeronautics: Paul E. Garber, assistant curator.
Section of Mineral Technology: Carl W. Mitman, in charge.
Division of Textiles: Frederick L. Lewton, curator; Mrs. E. W. Rosson, aid.
Section of Wood Technology: William N. Watkins, assistant curator.
Section of Organic Chemistry:
Division of Medicine: Charles Whitebread, assistant curator.
Division of Graphic Arts: R. P. Tolman, curator.
Section of Photography: A. J. Olmsted, assistant curator.

DIVISION OF HISTORY: T. T. Belote, curator; Charles Carey, assistant curator; Mrs. C. L. Manning, philatelist.

ADMINISTRATIVE STAFF

Chief of correspondence and documents.—H. S. BRYANT.
Assistant chief of correspondence and documents.—L. E. COMMERFORD.
Superintendent of buildings and labor.—R. H. TREMBLY.
Assistant superintendent of buildings and labor.—CHARLES C. SINCLAIR.
Editor.—PAUL H. OEHSER.
Engineer.—C. R. DENMARK.
Accountant and auditor.—N. W. DORSEY.
Photographer.—A. J. OLMSTED.
Property clerk.—LAWRENCE L. OLIVER.
Assistant librarian.—LEILA F. CLARK.

NATIONAL GALLERY OF ART

Trustees:
- The CHIEF JUSTICE of the UNITED STATES.
- The SECRETARY OF STATE.
- The SECRETARY of the TREASURY.
- The SECRETARY of the SMITHSONIAN INSTITUTION.
- PAUL MELLON.
- DAVID K. E. BRUCE.
- DUNCAN PHILLIPS.
- DONALD D. SHEPARD.
- FERDINAND L. BELIN.

President.—PAUL MELLON.
Vice president.—DAVID K. E. BRUCE.
Secretary and treasurer.—DONALD D. SHEPARD.
Director.—DAVID E. FINLEY.

NATIONAL COLLECTION OF FINE ARTS

Acting director.—RUEL P. TOLMAN.

FREER GALLERY OF ART

Director.—JOHN ELLERTON LODGE.
Associate in archeology.—CARL WHITING BISHOP.
Assistant director.—GRACE DUNHAM GUEST.
Associate in research.—ARCHIBALD G. WENLEY.
Superintendent.—JOHN BUNDY.

BUREAU OF AMERICAN ETHNOLOGY

Chief.—MATTHEW W. STIRLING.
Senior ethnologists.—JOHN P. HARRINGTON, TRUMAN MICHELSON, JOHN R. SWANTON.
Senior archeologist.—FRANK H. H. ROBERTS, Jr.
Senior anthropologist.—JULIAN H. STEWARD.
Editor.—STANLEY SEARLES.
Librarian.—MIRIAM B. KETCHUM.
Illustrator.—EDWIN G. CASSEDY.

INTERNATIONAL EXCHANGES

Secretary (in charge).—CHARLES G. ABBOT.
Chief clerk.—COATES W. SHOEMAKER.

NATIONAL ZOOLOGICAL PARK

Director.—WILLIAM M. MANN.
Assistant director.—ERNEST P. WALKER.

ASTROPHYSICAL OBSERVATORY

Director.—CHARLES G. ABBOT.
Assistant director.—LOYAL B. ALDRICH.
Senior astrophysicist.—WILLIAM H. HOOVER.

DIVISION OF RADIATION AND ORGANISMS

Director.—Charles G. Abbot.
Assistant director.—Earl S. Johnston.
Senior physicist.—Edward D. McAlister.
Senior mechanical engineer.—Leland B. Clark.
Associate plant physiologist.—Florence E. Meier.

REPORT OF THE SECRETARY OF THE SMITHSONIAN INSTITUTION

C. G. ABBOT

FOR THE YEAR ENDED JUNE 30, 1938

To the Board of Regents of the Smithsonian Institution.

GENTLEMEN: I have the honor to submit herewith my report showing the activities and condition of the Smithsonian Institution and the Government bureaus under its administrative charge during the fiscal year ended June 30, 1938. The first 15 pages contain a summary account of the affairs of the Institution, and appendixes 1 to 11 give more detailed reports of the operations of the National Museum, the National Gallery of Art, the National Collection of Fine Arts, the Freer Gallery of Art, the Bureau of American Ethnology, the International Exchanges, the National Zoological Park, the Astrophysical Observatory, the Division of Radiation and Organisms, the Smithsonian library, and of the publications issued under the direction of the Institution. On page 121 is the financial report of the executive committee of the Board of Regents.

OUTSTANDING EVENTS

The past year witnessed a further stimulus to the art feature of the Smithsonian Institution in the passage by Congress of a resolution authorizing the President to designate a tract of land on the Mall for a Smithsonian Gallery of Art and authorizing an appropriation of $40,000 to obtain preliminary plans for such a building. It is the expectation that the building itself will be financed by private funds. The year also marked the completion of the foundations of the new National Gallery of Art now under construction which is to house the Andrew W. Mellon art collection given by Mr. Mellon to the Nation through the Smithsonian Institution. The building is expected to be completed in 1940. The Smithsonian solar observing station on Mount St. Katherine in Egypt was abandoned owing to the excessive isolation of that station and other cogent reasons, and construction of a new station on Burro Mountain near Tyrone in New Mexico was begun. June 1938 marked the completion of 2 full years of the Smithsonian radio program in cooperation with the United States Office of Education. These educational broadcasts have con-

tinued in favor with a very large listening audience as witnessed by the nearly quarter of a million letters received as the result of the program.

Among the large amount of material received by the National Museum, an outstanding accession is a collection of mollusks obtained through the Frances Lea Chamberlain fund which numbered well over a million specimens. The Bureau of American Ethnology dispatched an expedition to South America to make extensive studies of the Indian tribes of the western part of that continent. New apparatus and new methods have been developed in the Division of Radiation and Organisms, and investigations have yielded important results particularly in the field of photosynthesis.

The Board of Regents lost three of its members by death, Senator Joseph T. Robinson, Ambassador Robert W. Bingham, and Augustus P. Loring. To fill the vacancies thus created, three new members were appointed, namely, Senator Alben W. Barkley, of Kentucky; Dr. Harvey N. Davis, of New Jersey; and Dr. Arthur H. Compton, of Illinois.

SUMMARY OF THE YEAR'S ACTIVITIES OF THE BRANCHES OF THE INSTITUTION

National Museum.—The total appropriation for the maintenance of the Museum was $775,720, an actual increase of $11,750 over the previous year. Specimens added to the collections, mainly as gifts or through Smithsonian expeditions, numbered 312,729. In this large amount of new material some of the more important accessions were as follows: In anthropology, nearly a hundred vessels and fragments from Honduras, obtained by the joint expedition with the Peabody Museum of Harvard University, and other archeological collections from Denmark, South Africa, and the Temple Mound in Le Flore County, Okla.; in biology, large additions to the collections of mammals, birds, reptiles, fishes, marine invertebrates, and insects, the latter including 54,000 insects transferred from the United States Bureau of Entomology and Plant Quarantine; in geology, specimens representing 62 distinct meteoric falls, largely purchased by the Roebling Fund, 790 specimens pertaining to mineralogy and petrology obtained through the Chamberlain Fund and the Canfield Fund, and an unparalleled collection of Devonian invertebrates made by Dr. G. Arthur Cooper and Preston Cloud in the Lower Peninsula of Michigan; in arts and industries, the first cable car to operate in Seattle, Wash. (1889), presented by the city of Seattle, 1,500 specimens pertaining to textiles, and a number of models of famous airplanes added to the aeronautical collection; and in history, more than 2,500 objects of historic and antiquarian value, including a num-

ber of objects relating to the scientific career of Dr. Charles D. Walcott, fourth Secretary of the Smithsonian Institution, the gift of Mrs. Walcott. A number of expeditions went out during the year in the interests of the Museum's researches in anthropology, biology, and geology. These were financed principally by Smithsonian private funds or by the assistance of friends of the Museum. Seventeen special exhibitions were held during the year under the auspices of various educational, scientific, and governmental agencies. The number of visitors to the several Museum buildings totaled 2,408,170, an increase of 119,638 over the previous year. The Museum published an annual report, 5 bulletins, and 19 Proceedings separates.

National Gallery of Art.—The first annual report of the National Gallery of Art reviews the establishment of the Gallery by joint resolution of Congress following the munificent gift to the Nation by the late Andrew W. Mellon of his great collection of art works, together with funds for the erection of a gallery building and for an endowment. The trustees announced the death of Andrew W. Mellon and S. Parker Gilbert, leaving two vacancies on the board which were filled by the election of Paul Mellon and Ferdinand Lammot Belin as general trustees. An organization meeting of the trustees was held on March 9, 1938, at which bylaws were adopted and executive officers were elected as follows: Paul Mellon, president; David K. E. Bruce, vice president; Donald D. Shepard, secretary and treasurer; and David E. Finley, director. Executive, acquisitions, and finance committees were named. At the close of the fiscal year the foundations of the gallery were substantially completed, and it is expected that the building will be completed by September 1940. A list of the paintings in the Mellon collection, now in storage at the Corcoran Gallery of Art, is presented in the report.

National Collection of Fine Arts.—The National Collection of Fine Arts is the name used to designate the art collections administered by the Smithsonian Institution with the exception of those that will be included in the National Gallery of Art, now under construction. A bill authorizing the Institution to obtain plans for a building to contain these collections and to be known as the "Smithsonian Gallery of Art" was passed at the last session of Congress. The bill also authorized the President to select a site for the gallery on the Mall between Fourth and Fourteenth Streets and authorized the soliciting of funds for its construction and for an endowment for the purchase of works of art. The seventeenth annual meeting of the National Gallery of Art Commission was held on December 7, 1937. As the name "National Gallery of Art" has been assigned to the gallery building now being erected to contain the Mellon art collections, the name of the Commission was changed to "Smithsonian

114728—39——2

Art Commission." A wood gravure of "Rockwell Studio," by Macowin Tuttle, was accepted by the Commission for the collection. Five miniatures were acquired through the Catherine Walden Myer fund. Six special exhibitions were held as follows: The art of the Mexican school children, 262 items; joint exhibition of the Twenty Women Painters and the Landscape Club, of Washington, D. C.; 74 water colors by William Spencer Bagdatopoulos; 85 paintings, 20 framed and 41 unframed water colors, 34 etchings, and 33 pieces of sculpture from the National Collection of Fine Arts; 3 portraits by Henrique Medina; and 260 naval historical prints from the Eberstadt Collection.

Freer Gallery of Art.—Additions to the collections included Chinese bronze, gold, and jade objects; Arabic manuscripts; Chinese, Indian, and Persian paintings; Chinese porcelain; Persian pottery; and Egyptian stone sculpture. The year's curatorial work has been devoted to the study of Chinese, Japanese, Arabic, Persian, Aramaic, and Armenian art objects and of associated texts, inscriptions, or seals. The results of these studies have been incorporated in the Gallery records. Many similar objects have been brought or sent to the Director by their owners for expert opinion on their identity, age, etc. Changes in exhibition in the Gallery have involved a total of 75 objects. The number of visitors for the year was 120,427. Two lectures on Musulman painting were given by Eustache de Lorey, of Paris; 9 groups were given instruction in the study rooms, and 10 groups were given docent service in the exhibition galleries.

Bureau of American Ethnology.—Mr. Stirling, chief, besides his administrative duties, made a reconnaissance trip to Mexico, during which he selected a site in the Canton of Tuxtlas south of Veracruz for archeological excavation during the coming year. Dr. Swanton devoted most of the year to field work and investigations relating to his work as chairman of the United States De Soto Expedition Commission. Dr. Michelson undertook field work among the Montagnais-Naskapi Indians of the northern shore of the St. Lawrence River and vicinity. Dr. Harrington completed a comparative study of the Tano-Kiowan family of languages. Dr. Roberts continued his archeological work at the Lindenmeier site in northern Colorado, where he unearthed a large collection of specimens relating to Folsom man, so far as known the earliest of New World inhabitants. Dr. Steward completed his final report on the tribes of the Great Plains-Plateau area. In April 1938, he left for Ecuador to begin extensive ethnological studies in the western part of South America. The Bureau published an annual report and three bulletins.

International Exchanges.—The International Exchange Service under the Smithsonian Institution acts as the official agency of the

United States for the interchange with other countries of governmental and scientific documents. During the year the service handled 719,121 packages of such matter, an increase of 61,775 over the previous year. The weight of these packages was 656,119 pounds. The Government franking privilege was extended to cover a number of South and Central American countries, and packages for those countries were therefore sent direct to their destinations by mail instead of through the respective exchange bureaus. Shipments of exchanges to Spain have been suspended since August 1936, and those to China since August 1937. At the close of the year, however, a large consignment was being prepared for shipment to the Chinese Bureau of International Exchanges, which had moved its office from Nanking to Chungking.

National Zoological Park.—The outstanding feature of the year was the addition to the collection of the large number of animals, birds, and reptiles brought back by the National Geographic Society-Smithsonian Expedition to the East Indies. The actual number of specimens was 879, consisting of 121 mammals of 46 species, 649 birds of 93 species, and 109 reptiles of 30 species. The new large mammal house described in last year's report was stocked with animals during August and September 1937, the difficult task of transferring such large creatures as elephants, hippopotamuses, and rhinoceroses being accomplished without mishap. Visitors for the year again increased in number, the total reaching 3,127,650. This included 1,374 organizations, mainly schools, with a total of 70,371 individuals. Among the additions to the animal collection may be mentioned 34 mammals born and 30 birds hatched in the Park. The total number of animals in the collection at the close of the year was 2,754, an increase of 412 over last year. The most urgent need of the Park is a new building for the restaurant and concession stand.

Astrophysical Observatory.—The main business of the year was the recomputation of all solar-constant values from 1923 to the present time. This immense task was nearly completed at the close of the year, and it is hoped that by January 1939 a homogeneous series of daily values will be available. A highly sensitive instrument to measure the distribution of energy in the spectra of some of the brighter stars was constructed by Dr. Abbot and Mr. Hoover, and in May 1938 Mr. Hoover took the apparatus to Mount Wilson, Calif., to make new measurements of the stellar spectrum energy and also to make studies of the growth of plants in monochromatic rays. By way of anticipating next year's report, it may be said that gratifying progress was made in both researches. At the request of the Weather Bureau, construction was begun of a duplicate of the atmospheric turbidity and moisture apparatus used by the Institution in testing

the desirability of mountain sites for solar observatories. Dr. Abbot made further progress in the development of devices for utilizing solar radiation. The solar-radiation station on Mount St. Katherine in Egypt was abandoned for several reasons in December 1937, and a new station was located on Burro Mountain near Tyrone, N. Mex. It is hoped to begin observations there by November 1938. Dr. Brian O'Brien, aided by Smithsonian grants, has made further progress in the development of methods and apparatus for measuring solar variation in the ultraviolet from sounding balloons, and he hopes soon to be able to compare this method with the results of the Smithsonian solar-constant observations.

Division of Radiation and Organisms.—Many investigations relating to plant growth and radiation have been fruitfully pursued during the year. An improved method has been developed for measuring plant growth substances concerned in the bending of plants toward the light. Several members of the staff have collaborated in preparing a new automatic apparatus for measuring and recording photosynthesis continuously, as well as an apparatus for the determination of chlorophyll. Preparations are under way for the investigation of photosynthesis in algae. Studies were continued of mixtures of artificial lights suitable to promote satisfactory plant growth under laboratory conditions. Dependence of the induction periods in the photosynthesis of wheat on the length of previous dark exposures was further investigated, and in addition important results were obtained on the chlorophyll—CO_2 ratio during photosynthesis. Members of the staff published five papers on the results of these and other investigations during the year.

THE ESTABLISHMENT

The Smithsonian Institution was created by act of Congress in 1846, according to the terms of the will of James Smithson, of England, who in 1826 bequeathed his property to the United States of America "to found at Washington, under the name of the Smithsonian Institution, an establishment for the increase and diffusion of knowledge among men." In receiving the property and accepting the trust, Congress determined that the Federal Government was without authority to administer the trust directly, and, therefore, constituted an "establishment" whose statutory members are "the President, the Vice President, the Chief Justice, and the heads of the executive departments."

THE BOARD OF REGENTS

During the year the Board of Regents lost three of its members by death, namely, Senator Joseph T. Robinson, of Arkansas, on July 14, 1937; Ambassador Robert W. Bingham, of Kentucky, on December

18, 1937; and Mr. Augustus P. Loring, of Massachusetts, on March 17, 1938. Senator Alben W. Barkley, of Kentucky, was appointed by the President of the Senate on November 15, 1937, to succeed Senator Robinson; by joint resolution of Congress approved June 15, 1938, Dr. Harvey N. Davis, of New Jersey, was appointed to succeed Ambassador Bingham; and by joint resolution approved June 20, 1938, Dr. Arthur H. Compton, of Illinois, was appointed to succeed Mr. Loring. Also by joint resolution approved June 20, 1938, Hon. R. Walton Moore, of Virginia, was reappointed to succeed himself.

The roll of Regents at the close of the year was as follows: Charles Evans Hughes, Chief Justice of the United States, Chancellor; John N. Garner, Vice President of the United States; members from the Senate—M. M. Logan, Charles L. McNary, Alben W. Barkley; members from the House of Representatives—T. Alan Goldsborough, Charles L. Gifford, Clarence Cannon; citizen members—Frederic A. Delano, Washington, D. C.; John C. Merriam, Washington, D. C.; R. Walton Moore, Virginia; Roland S. Morris, Pennsylvania; Harvey N. Davis, New Jersey; Arthur H. Compton, Illinois.

Proceedings.—The annual meeting of the Board of Regents was held on January 13, 1938. The Regents present were Chief Justice Charles Evans Hughes, Chancellor; John N. Garner, Vice President of the United States; Senators M. M. Logan and Alben W. Barkley; Representatives T. Alan Goldsborough, Charles L. Gifford, and Clarence Cannon; citizen Regents Frederic A. Delano and John C. Merriam; and the Secretary, Dr. Charles G. Abbot.

The Secretary presented his annual report, detailing the activities of the several Government branches and of the parent institution during the year, and Mr. Delano presented the report of the executive committee, covering financial statistics of the Institution. The Secretary also presented the annual report of the National Gallery of Art Commission, the name of which was changed, by a resolution adopted by the Regents at this meeting, to the Smithsonian Art Commission.

In his usual special report the Secretary presented to the Regents a brief review of important activities carried on by the Institution and members of the staff during the year.

In addition to the annual meeting, there was a special meeting of the Board of Regents on May 11, 1938, at which the following Regents were present: Chief Justice Charles Evans Hughes, Chancellor; Representatives T. Alan Goldsborough, Charles L. Gifford, and Clarence Cannon; citizen Regents Frederic A. Delano, R. Walton Moore, and Roland S. Morris; and the Secretary, Dr. Charles G. Abbot. This meeting was called to consider several urgent matters

that had arisen, including a pending joint resolution of Congress (which was afterward approved on May 17, 1938) setting apart public ground for the Smithsonian Gallery of Art, and establishing the Smithsonian Gallery of Art Commission, to make preliminary investigations and to secure appropriate designs, by competition or otherwise, for a Smithsonian Gallery of Art. The joint resolution also authorized an appropriation of $40,000 for expenses of the Commission, which amount was included in the deficiency appropriation bill approved June 25, 1938.

FINANCES

A statement will be found in the report of the executive committee, page 121.

MATTERS OF GENERAL INTEREST

THE SMITHSONIAN GALLERY OF ART

In my last report I spoke of a resolution introduced at the first session of the Seventy-fifth Congress to establish a Smithsonian Gallery of Art to house the national art collections. The resolution did not pass that session of Congress, but it was introduced again at the third session, passed both houses of Congress, and was approved by the President on May 17, 1938. The resolution authorized the President to set apart ground for such a gallery on the Mall between Fourth and Fourteenth Streets and Constitution and Independence Avenues. A commission was set up, to be called the Smithsonian Gallery of Art Commission, who were authorized to secure appropriate designs for a gallery building, and $40,000 was authorized to be appropriated for this purpose. The Regents of the Institution were authorized to solicit and receive subscriptions of funds for the construction of a building. In addition to providing space for the present National Collection of Fine Arts, administered by the Institution, and other art works belonging to the Government, the Smithsonian Gallery of Art is authorized by the resolution to hold public exhibitions, to acquire and sell contemporary works of art, to employ artists and other personnel, and to award scholarships.

The $40,000 authorized to be appropriated was actually provided in the Second Deficiency Act approved June 25, 1938.

The Smithsonian Gallery of Art Commission as designated in the resolution held its first meeting on May 25, 1938, at the Smithsonian Institution. Five of the eight members constituting the Commission were present, namely, Edward Bruce, Frederic A. Delano, Hon. Kent E. Keller, Charles L. Borie, Jr., and Dr. Charles G. Abbot. Two of the remaining members, Senators Alben W. Barkley and Gilmore D. Clarke, were unable to be present, and the eighth mem-

ber, a representative of the Board of Regents of the Institution, had not yet been designated. Mr. Delano was elected chairman of the Commission and Dr. Abbot secretary. A ways and means committee was appointed to consider the matter of soliciting funds from prospective donors for the construction of the gallery building, and an outline of the characteristics of a desirable type of building was presented by the chairman. The meeting adjourned subject to call by the chairman.

The Smithsonian Institution is indeed gratified that at last there is real promise of a suitable gallery building to house the valuable art collections in its custody formerly known as the National Gallery of Art and since 1937 as the National Collection of Fine Arts. Such a gallery, together with the National Gallery of Art now under construction and the Freer Gallery of Art, all associated with the Smithsonian Institution, will undoubtedly go far toward placing America among the forefront of nations in the field of art and will eventually make of the Nation's Capital an art center comparable with those of the Old World.

SMITHSONIAN RADIO PROGRAM

In June 1938 was completed the second full year of "The World is Yours," the weekly radio program put on the air by cooperation between the United States Office of Education, the National Broadcasting Co., and the Smithsonian Institution, with the financial support of the Works Progress Administration. The series was begun in June 1936 as an experiment in the field of educational radio. The Smithsonian editorial office worked out a widely diversified but carefully balanced series of subjects in the various fields of the Institution's activities—science, invention, history, and art—and these subjects were presented to listeners as half-hour dramatizations every Sunday over an NBC network. The number of stations carrying the programs was small at first, but increased gradually until in June 1938 "The World is Yours" went on the air over 57 stations and 2 short-wave stations.

In my last report were listed the subjects covered in the first year's programs. From July 1, 1937, to June 30, 1938, the following subjects were presented:

	1937
Revolutionary Relics	July 4
Life in the Sea	July 11
Pharmaceutical Products	July 25
Automobiles	Aug. 1
Men of Science	Aug. 8
Medals	Aug. 15
Glass	Aug. 22
Egyptian Antiquities	Aug. 29
Rubber	Sept. 5
Refrigeration	Sept. 12
Cutlery	Sept. 19
Surgery	Sept. 26
Tin	Oct. 3
Flying the Oceans	Oct. 10
Lace	Oct. 17
Radiation	Oct. 24
Famous Swords	Oct. 31
Science Advance of the Year	Nov. 7
John Smith and the Virginia Indians	Nov. 14
Romance of Surveying	Nov. 21
Capturing Live Animals in Sumatra	Nov. 28
Diamond	Dec. 5
Aztec Civilization	Dec. 12
Drugs and Medicines	Dec. 19
Christmas in the Colonies	Dec. 26
	1938
The True De Soto	Jan. 2
Masters Behind the Mellon Masterpieces	Jan. 9
Land versus Weather	Jan. 16
The Saga of the Sewing Machine	Jan. 23
Whales, Largest of Mammals	Jan. 30
Four Principles of Mechanics	Feb. 6
Snakes, Big and Little	Feb. 13
The Lincoln Legend	Feb. 20
The Story of Electricity	Feb. 27
Man Against Insects	Mar. 6
Conquest Underground	Mar. 13
Rockets and Planets	Mar. 20
Saving the Forests	Mar. 27
Birds of Prey	Apr. 3
Introducing the Universe	Apr. 10
The Inca Empire of the Sun	Apr. 17
Silver Through the Centuries	Apr. 24
Exploration for Science	May 1
Primitive Music	May 8
Air Mail	May 15
American Food Plants	May 22
Rare Metals	May 29
Twentieth Century Physics	June 5
Jacques Marquette on the Mississippi	June 12
Industrial Chemistry	June 19
Life Under the Microscope	June 26

According to the large amount of mail received at the Office of Education after each week's program goes on the air, the series has maintained a widespread popularity among listeners of all ages and occupations in the United States, Canada, and some foreign countries. During the two years "The World is Yours" has been on the air, close to a quarter of a million letters have been received, only a very small fraction of 1 percent of which have contained adverse criticism. Many, on the other hand, have been enthusiastic in their praise of the efforts of the Smithsonian and the Office of Education to make available via radio the wealth of information in science, history, and art contained in the exhibits and laboratories of the Smithsonian Institution.

Again I wish to express the Institution's gratitude to the Office of Education, the National Broadcasting Company, and the W. P. A. for making this educational radio program possible. It supplements admirably the Institution's previous methods of accomplishing one of its primary functions, the diffusion of knowledge. The financial support of the W. P. A. now seems assured for the continuation of the program during the coming fiscal year.

WALTER RATHBONE BACON TRAVELING SCHOLARSHIP

The Walter Rathbone Bacon Traveling Scholarship of the Smithsonian Institution was awarded for a third consecutive year commencing June 15, 1937, to Dr. Richard E. Blackwelder.

At the beginning of the period Dr. Blackwelder spent about 6 weeks in England where he studied the West Indian collections of Staphylinidae belonging to the British Museum and to Dr. Malcolm Cameron. Upon his return to this country he prepared his final report which takes the form of a revision of the West Indian components of the beetle family Staphylinidae.

SMITHSONIAN INSTITUTION EXHIBIT AT THE PARIS INTERNATIONAL EXPOSITION, 1937

In order to conform to the general theme of the Paris International Exposition, that is, "Arts and Technique of Modern Life," the Smithsonian Institution selected as its contribution a small exhibit which aimed to show the technique and variety of media originally used by the North American Indian for his artistic expressions. It was entitled "Arts and Crafts of the North American Indian." The exhibit formed one of a series of Federal exhibits occupying a portion of the United States Building in the Exposition grounds.

The exhibit consisted of 41 carefully selected specimens from the vast ethnological collections of the United States National Museum. They included examples indicative of the Indians' skill in wood and

stone carving; skin dressing; application of vegetable dyes; basket weaving; embroidery work with split and died porcupine quills and with glass beads; sewed feather designs; and free-hand painting of decorative and symbolic designs. The craftsmanship of some 15 American Indian tribes was represented in the exhibit including the Comanche, Sioux, Cheyenne, Shoshone, Poma, Apache, Chippewa, and Kiowa.

The exhibit was arranged in two exhibition cases especially designed for the purpose, and with each object there were placed brief descriptive labels in both English and French.

SEVENTH ARTHUR LECTURE

The seventh Arthur lecture, The Sun and the Atmosphere, was given by Dr. Harlan True Stetson, of the Massachusetts Institute of Technology, in the auditorium of the National Museum on the evening of February 24, 1938. Dr. Stetson, one of the world's leading authorities on the solar-terrestrial relationship, discussed particularly the sunspots and their effect upon various terrestrial matters. The lecture is published in the General Appendix to the present report (p. 149).

The Arthur lecture was provided for in the will of the late James Arthur, of New York City, who left to the Institution in 1931 a sum of money, part of the income from which should be used for an annual lecture on some aspect of the study of the sun.

EXPLORATIONS AND FIELD WORK

Twenty-four expeditions during the last calendar year took Smithsonian representatives to 13 States in the United States and many foreign countries to collect specimens and data needed in the scientific researches of the Institution.

Dr. Charles W. Gilmore directed exploration for dinosaur and mammalian fossils in Utah and Arizona. Dr. Charles E. Resser studied the Cambrian rocks of New York, Vermont, and Quebec. Dr. G. Arthur Cooper collected fossils needed in current investigations in Michigan, Pennsylvania, New York, and Canada. E. P. Henderson, representing the Smithsonian at the International Geological Congress in Moscow, had an opportunity to study the minerals of Russia.

Dr. Alexander Wetmore visited Venezuela to observe the bird life of that part of South America. A collection of birds, including the very rare Asiatic fin foot and the Malayan ring plover, was made by H. G. Deignan in Siam. Gerrit S. Miller, Jr., spent 3 months in Panama collecting animals and plants. Watson M. Perrygo, continuing the work begun last year, went to Tennessee to obtain bird and mammal specimens needed for the Museum collections. Dr.

William M. Mann directed the National Geographic Society-Smithsonian Expedition to the East Indies to collect living animals, birds, and reptiles for the National Zoological Park. William N. Beach obtained in Alaska some fine specimens of moose and caribou for the National Museum's exhibition series. Capt. Robert A. Bartlett, who for several years has been carrying on investigations in the Arctic region, visited the west coast of Greenland, sending back to the Smithsonian many specimens of marine life as well as specimens of birds and plants. Dr. Waldo L. Schmitt participated in an expedition to the West Indies and obtained, in addition to many new marine forms, two porpoises, which are among the rarest things in museums. Dr. Paul Bartsch took part in an expedition for the collection of marine organisms in West Indian waters. Dr. Bartsch also continued his heredity experiments, begun in 1912, using young specimens of a species of fresh-water mollusk as his subjects and various rivers and creeks in Virginia and West Virginia as breeding grounds. Dr. Edward A. Chapin collected some 50,000 specimens of insects on the Island of Jamaica, among them three species of scarabs new to science. Austin H. Clark hunted the "invisible butterfly," the Brazilian skipper, in Virginia, and although he was unable to find one of these butterflies, he obtained specimens of other rare species. Paul S. Conger explored the lakes of northern Wisconsin for diatoms.

Dr. Aleš Hrdlička went again to Alaska to further his study of the earliest occupation of that region, and spent 3 months on a series of the Aleutian Islands and on the Commander Islands, collecting 51 boxes and barrels of important anthropological material. Dr. Herbert W. Krieger conducted an archeological expedition to explore a large shell mound on the Island of Anegada, the most northerly of the British Virgin Islands, the objective being a comparison of the Indian relics recovered there with the large collection obtained by previous Smithsonian expeditions to the West Indies. Waldo R. Wedel inaugurated an archeological survey of Kansas, spending 3½ months in reconnaissance excavations in the northeastern part of the State and unearthing a wealth of important and varied archeological remains. David I. Bushnell, Jr., visited ancient Indian sites on the banks of the Rappahannock in Virginia and recovered many cultural objects shedding light on the manners and ways of life of the early inhabitants of the valley. Dr. John R. Swanton engaged in two field trips for the purpose of tracing De Soto's trail across America to the Mississippi. Dr. Frank H. H. Roberts, Jr., obtained additional evidence at the Lindenmeier site in Colorado of the existence of Folsom man, one of the earliest known inhabitants of the New World. Dr. Truman Michelson spent the summer of 1937 among the Montagnais-Naskapi Indians in Canada for the purpose of complet-

ing a linguistic map showing the distribution and interrelations of the Cree and the Montagnais-Naskapi dialects.

PUBLICATIONS

The Institution and its branches issued during the year a total of 68 publications. Of this number, 38 were issued by the Smithsonian proper, 26 by the National Museum, and 4 by the Bureau of American Ethnology. The titles, authors, and other information regarding all these publications will be found in the report of the editor, appendix 11. The total number of copies of publications distributed was 129,478.

The Institution depends in large part upon its series of publications to carry out one of its primary functions—the diffusion of knowledge. Its other means—its museum and art gallery exhibits, its extensive correspondence, its science news releases, and educational radio programs—are also important, but in its publications are presented in permanent form the results of researches by the scientific staffs of the Institution, the National Museum, the Bureau of American Ethnology, and other branches. These publications are regularly distributed free to a large list of libraries and educational institutions, where they are readily available to students and to other scientific workers.

Among the larger publications of the year there may be mentioned as particularly outstanding a work by Henry B. Collins, Jr., entitled "Archeology of St. Lawrence Island, Alaska," in which he summarizes the results of several years' work in the far north on the prehistory of the Eskimo; "Preliminary Report on the Smithsonian Institution-Harvard University Archeological Expedition to Northwestern Honduras, 1936," by William Duncan Strong, Alfred Kidder II, and A. J. Drexel Paul, Jr.; "The Oxystomatous and Allied Crabs of America," by Mary J. Rathbun, another in her series of monographs on American crabs; and "Historical and Ethnographical Material on the Jivaro Indians," by M. W. Stirling, an account of the Jivaro head-hunters of Ecuador based on first-hand information obtained by Mr. Stirling on a recent expedition to the region occupied by these Indians.

LIBRARY

Accessions to the Smithsonian library for the year numbered 10,892 items, received mostly through exchange and gift. These bring the total number of items in the library to 887,414, exclusive of thousands of volumes incomplete or unbound. The outstanding gift of the year was a collection of 1,186 volumes and pamphlets on the history and culture of China, presented by Mrs. William Woodville Rockhill. The Geophysical Laboratory presented 3,312 miscellaneous publications, the American Association for the Advancement of Science, 653; and

the American Association of Museums, 209. Besides the extensive exchange work, which involved 25,264 packages of publications, the staff of the library recorded 23,992 periodicals, cataloged 6,449 publications, prepared and filed 42,568 catalog and shelf list cards, made 11,380 loans, and did a considerable amount of work on the union catalog. The chief need of the library is more funds for binding.

Respectfully submitted.

C. G. Abbot, *Secretary.*

APPENDIX 1

REPORT ON THE UNITED STATES NATIONAL MUSEUM

Sir: I have the honor to submit the following report on the condition and operation of the United States National Museum for the fiscal year ended June 30, 1938:

Funds provided for the maintenance of the National Museum for the year totaled $775,720, representing an increase of $20,250 over the previous year. Owing to a compulsory administrative deduction of $8,500, however, this increase actually amounted only to $11,750.

COLLECTIONS

Material added to the Museum collections during the year came in 1,713 separate accessions totaling 312,729 specimens. These additions were mostly gifts from individuals or represented expeditions sponsored by the Smithsonian Institution. The specimens were distributed among the five departments as follows: Anthropology, 2,162; biology, 244,761; geology, 60,927; arts and industries, 2,297; and history, 2,582. All the accessions are listed in detail in the full report on the Museum, printed as a separate document, but the more important are summarized as follows:

Anthropology.—Archeological accessions of importance included nearly one hundred vessels and fragments from Honduras, obtained by the 1936 joint expedition with the Peabody Museum of Harvard University; a lot of Stone Age, Bronze Age, and Iron Age objects from Denmark; Neolithic stone implements from South Africa; and a collection of artifacts from the Temple Mound in Le Flore County, Okla.

As in previous years, C. C. Roberts donated many articles of ethnological interest from West Africa. Various objects came from the Eskimo in Alaska and the Hudson Bay region. Navaho, Pueblo, and Ojibwa blankets, beadwork, pottery, and baskets came from several donors. Seventy-eight ceramic specimens were received, 10 musical instruments, and 57 objects representing period art and textiles.

In the division of physical anthropology 555 specimens, including much skeletal material, were received. Of these, 291 were obtained by Dr. Aleš Hrdlička in Alaska during his field explorations; 144 from an Indian site in Stafford County, Va., were donated by the

late Judge W. J. Graham; and 67 from another important Indian site at Accokeek, Md., were presented by Mrs. A. L. L. Ferguson.

Biology.—Biological specimens added during the year numbered over 240,000, and the total in this department now exceeds 12,500,000. Of the mammals received, more than 1,200 were transferred from the United States Biological Survey. A particularly welcome gift was that of a mounted specimen of a Montana grizzly bear of a form now extinct (true *Ursus horribilis*) from Dr. C. Hart Merriam. A fine lot of cetacean material also was received. Important avian accessions included birds collected in Venezuela by Dr. Alexander Wetmore, in Siam by H. G. Deignan, in Tennessee by W. M. Perrygo, and in China by Dr. D. C. Graham. New reptile and amphibian material came from many places, notably reptiles from the Lesser Antilles, Siam, Ceram, and Sumatra, Tennessee, Florida, Texas, Maine, and Vermont; frogs and toads from Brazil; and salamanders from Central America. About 5,100 fishes were transferred to the Museum collection from the United States Bureau of Fisheries; 12,780 specimens from the middle Atlantic coast were presented by the Bingham Oceanographic Foundation of Yale University and the United States Bureau of Fisheries; the Carnegie Institution of Washington gave 6,200 fishes collected by the late Dr. W. H. Longley from the Tortugas and the Dutch West Indies; and many hundreds of others came from the National Geographic-Smithsonian Expedition in Sumatra, the Smithsonian-Hartford Expedition of 1937, the Tennessee Valley Authority, the United States Biological Survey, the Bass Biological Laboratory, and H. G. Deignan, to name but a few of the many donors. The more important accessions of insects include the following: The Blackmore collection of Lepidoptera (2,111 specimens), the Quirsfeld collection of weevils (1,157 specimens), 15,000 ants donated by Dr. M. R. Smith, 10,000 Chinese insects collected by Dr. D. C. Graham, and 54,000 insects transferred from the United States Bureau of Entomology and Plant Quarantine. The 15,300 marine invertebrates added consisted mostly of specimens new to the collections or type material. Over 1,000 specimens of marine invertebrates were added through the explorations of Capt. Robert A. Bartlett in West Greenland in 1937, and another large group from the West Indies resulted from the Smithsonian-Hartford Expedition. The outstanding accession of mollusks was the Bohumil Shimek collection of loess shells, obtained through the Frances Lea Chamberlain Fund. This collection, of both recent and fossil species, consisted of nearly 25,000 lots and aggregated more than a million individual specimens. About 36,500 plants were added to the herbarium collections, from many points of North, South, and Central America.

Geology.—Important accessions in mineralogy were made possible by several Smithsonian funds. Through the Canfield fund were purchased minerals from Japan, Sardinia, Rumania, Greece, Austria, California, Arkansas, Arizona, and Montana; through the Roebling fund, seven American diamonds; and through the Chamberlain fund, four cut gem stones. In all, 790 specimens pertaining to mineralogy and petrology were received. Seventy meteorite specimens, many purchased by the Roebling Fund, representing 62 falls new to the collection, were added during the year, the largest number since the acquisition of the Shepard collection in 1915.

In the field of vertebrate paleontology, the collections benefited especially by the field expedition of C. W. Gilmore, and by material presented by the United States Texas Centennial Commission. In all, 69 fossil vertebrates were added, including the partial skeleton of a very large sauropod dinosaur of the family Titanosauridae, the first to be found in North America.

Chiefly through the efforts of members of the staff, about 60,000 specimens were added to the collections in stratigraphic paleontology, the most extensive and valuable accession of the year in this field being an unparalleled collection of Devonian invertebrates made by Dr. G. Arthur Cooper and Preston Cloud in the Lower Peninsula of Michigan. Others came from the Chazyan rocks of northeastern New York and Quebec. Rare brachiopods were obtained from Canada and Nevada, and Devonian corals and crinoids from Michigan. Transfers from the United States Geological Survey included collections in Ozarkian, Canadian, and Chazyan brachiopods, numbering more than 22,000 specimens.

Arts and industries.—Models of the following airplanes were added to the aeronautical collections: The Vickers Vimy plane that made the first nonstop trans-Atlantic flight in 1919; the Sikorsky S-40, the first of the clipper planes on airways over Florida, the West Indies, and South America; the Wilford gyro; the low-wing tractor monoplane *Mohawk* made for Col. Charles A. Lindbergh; and several historic airmail planes, including the *Queen Bleriot* (1911), the Curtiss modified "R" (1916), and the Northrop airplane that held the 1934 record for transcontinental mail transport. The first cable car to operate in Seattle, Wash. (1889), was presented to the Museum by the City of Seattle. Several interesting original builders' models of watercraft also were received. Many miscellaneous objects pertaining to communication, metrology, refrigeration, photography, and tools and crafts continued to come in as gifts and loans, welcome additions to these sections, and nearly 1,500 specimens pertaining to textiles, organic chemistry, wood technology, and medicine were received during the year. To the graphic arts display were

added 321 specimens showing printing processes (in 8 exhibition cases) received from the United States Government Printing Office.

History.—More than 2,500 objects of historic and antiquarian value were received, chiefly portraits, costumes, medals, mementos, and furniture of historic characters. The series of awards and personal mementos was enriched by a number of objects relating to the scientific career of Dr. Charles D. Walcott, fourth Secretary of the Smithsonian Institution, a gift of Mrs. Walcott. Several pieces of parlor furniture made in Paris for President James Monroe in 1817 and used in the White House from then until 1937 were lent to the Museum by the White House for an indefinite period. The numismatic collection was increased by 366 coins and medals, including a bronze medal commemorating the invention of the bifocal lens by Benjamin Franklin in 1784. The philatelic collection was increased by the transfer from the Post Office Department of 2,088 specimens of foreign postage stamps, cards, and envelopes.

EXPLORATIONS AND FIELD WORK

The scientific explorations of the year by members of the Museum staff were financed principally by grants from the private funds of the Smithsonian Institution or by contributions from friends of the Institution. The investigations were varied in nature and brought highly important results in additions to scientific knowledge and in contributions of specimens to the national collections.

In May, Dr. Alexander Wetmore, Assistant Secretary, as representative of the Smithsonian Institution, and chairman of the official delegation of the United States, was in attendance at the Ninth International Ornithological Congress, held in Rouen, France. At the close of the meetings it was voted to hold the next Congress, which will come in 1942, in the United States. Dr. Wetmore was then elected President. Following the meetings he visited museums and laboratories in Switzerland, particularly in Bern and Basel, and later worked at the British Museum (Natural History) in London.

Anthropology.—During April and May 1938 Frank M. Setzler, head curator of the department of anthropology, continued an archeological program in the trans-Pecos area of southwestern Texas. Since 1931 Mr. Setzler has been attempting, as opportunity permitted, to outline the aboriginal culture status of the cave dwellers in the Big Bend region of Texas. His previous excavations at the mouth of the Pecos contributed largely to knowledge of the unusual physical types of this simple nonpottery-making horizon. This year, through the L. L. Wilson fund, he was enabled to excavate a large cave in the northeast corner of Terrell County. Though this produced no skeletal material, the 9-foot deposits of burnt rocks and

ashes contained sufficient aboriginal artifacts to show a direct cultural relationship with regions to the south and west in the Chisos Mountains and near Alpine. After examining additional material from the Guadelupe Mountains, in the Carlsbad Archeological and Historical Society Museum, and a small collection from caves around Albuquerque, N. Mex., Mr. Setzler concludes that this prehistoric phase has a much wider distribution than heretofore recognized, especially in the eastern part of New Mexico. The exact period of occupation of these caves can only be surmised; but since no evidence of European materials has been reported in association with the sandals, baskets, and other artifacts, he concludes that the caves were abandoned before any of the early Spanish explorers visited the area. Since most of their material culture comprises baskets instead of earthenware vessels, they may have become isolated before the manufacture of aboriginal pottery became so widespread and indispensable among the prehistoric inhabitants in either the Southwest or the Mississippi Valley. The chronological relationship, if any exists, between the Big Bend Cave Dwellers and the Basketmaker phase in northern New Mexico and Arizona as yet remains unsolved.

On October 14, Herbert W. Krieger, curator of ethnology, sailed from New York for Charlotte Amalie, St. Thomas, to conduct archeological investigations in the Virgin Islands under a grant from the Smithsonian Institution. The expedition was undertaken as a result of information conveyed by Robert Nichols, superintendent of agriculture of St. Thomas, to the effect that a large shell mound existed on the Island of Anegada, the northernmost of the British Virgin Islands. The immediate objective was an exploration of the Anegada mound, which required the cooperation of the United States Coast Guard Service. A survey of the shell mound led to the conclusion that the culture represented was similar to that of other nonpottery-producing cultures discovered on previous Smithsonian expeditions to the Dominican Republic, Haiti, and Cuba. At the conclusion of the Anegada survey a trial excavation was made of the Indian midden east of Road Town on the Island of Tortola. Later, excavations were carried out in considerable detail on the A. S. Fairchild property at Magens Bay on the Island of St. Thomas, and later at Ackles on United States Government property on the Island of St. Croix.

These investigations led to the discovery of three distinct cultures, all of which may be of Arawak origin—the shell culture on the Anegada site, the early Arawak culture type of the Road Town site and to a certain extent of the Magens Bay area, and the late Arawak culture of the Ackles site. An overlapping of the Arawak I and Arawak II phases was strikingly illustrated in the excavations at Magens Bay. A chronology of West Indian aboriginal cultures has consequently assumed form. The sequence of the three main culture types

just indicated permits of the dovetailing as subcultures for Arawak I (early Arawak) and for Arawak II (late Arawak) of the material from certain sites in the Dominican Republic and Haiti excavated by former Smithsonian expeditions from 1928 to 1931. It is quite clear that the shell middens of the caves of the south shore of Samaná Bay (Smithsonian expedition, 1928) and of the Île á Vache shell midden (Smithsonian expedition, 1931) are culturally related to the Anegada shell midden. The expedition to the Virgin Islands thus has crystallized tentative conclusions with regard to the classification of West Indian culture sequences based on numerous investigated sites.

Dr. Aleš Hrdlička, curator of physical anthropology, assisted by six students, spent the greater part of June, July, and August, 1937, in archeological investigations on the Aleutian Islands. After reaching the Aleutian Islands the party received permission to work in the Commander Islands in Soviet territory, but because of unforeseen circumstances the visit had to be very short. Although there was little time for scientific work, enough information was gained to encourage the arrangement for another visit. The Institution in its northern work is once more deeply indebted to the United States Coast Guard for its excellent cooperation, which made possible the work not only in the Aleutian Islands but in the Commander group. In 1938, again through the cooperation of the United States Coast Guard, archeological work was continued in the Aleutian Chain and was well under way at the close of the fiscal year.

From the beginning of the fiscal year until September 13, 1937, Dr. Waldo R. Wedel, assistant curator of archeology, was occupied in an archeological survey in Kansas, beginning a long-term program that is planned to cover a complete survey of the entire State in an attempt to establish the outlines of the aboriginal Indian cultures throughout that region. It should also reveal answers to some of the puzzling problems relating to prehistoric cultures in the Mississippi Valley and in the Western Plains. By using early documentary accounts some of the historic Indian sites can be definitely identified, and thereby they may reveal a complex of material culture traits that can be identified with their prehistoric antecedents. Dr. Wedel's investigations of 1937 included excavations at three village sites along the bluffs of the Missouri River and above Kansas City, and two in the Kansas River Valley near Manhattan. In the prolific site on Line Creek, northwest of Kansas City, evidences were found of an extended occupation of prehistoric origin containing two diagnostic types of earthenware vessels. One type has a general cord-roughened decoration, while directly associated with it was a superior ware bearing decorations closely comparable to the Hopewellian type

of the Mississippi Valley and never before reported as far west as Kansas City. An early Kansa Indian Village was also investigated near the old river town of Doniphan, Kans. This village was visited by early explorers in 1724 and again by Lewis and Clark in 1804. A few miles below the mouth of the Blue River a circular house site was excavated in an old Kansa village visited and described by Major Long's expedition in 1819. Dr. Wedel again resumed his explorations in Kansas on May 11, 1938, and was in the field at the close of the fiscal year.

Since Judge W. J. Graham's death on November 10, 1937, arrangements have been made for Dr. T. Dale Stewart, assistant curator of physical anthropology, to take over the excavations on an Indian site at Potomac Creek, Va., and to advance the work from the point reached by Judge Graham. During the latter part of the fiscal year Dr. Stewart made several visits to the site for preliminary surveys.

Biology.—Through the friendly cooperation of William N. Beach and J. Watson Webb, the National Museum has secured a valuable collection of large mammals from the Rainy Pass region beyond Mount McKinley in Alaska. In preparation for this work pack horses under charge of Harry Boyden were sent to Alaska in June. Mr. Beach and Mr. Webb, accompanied by W. L. Brown, chief taxidermist of the National Museum, arrived at McKinley Park Station on the Alaska Railroad on the evening of August 13 and continued through the park to join the pack outfit on the McKinley River. Work in this field continued until the middle of September and resulted in obtaining fine material for a habitat group of moose, which will be mounted for exhibition. The largest bull moose secured has a fine heavy set of horns with a spread of 65 inches. In addition, the party obtained caribou and other mammals much needed for the National Museum.

In continuation of work begun last year in West Virginia, Watson M. Perrygo, scientific aid, made collections of birds and mammals in Tennessee to obtain needed material for the National Museum. Mr. Perrygo left for the field early in April, accompanied by Carleton Lingebach as assistant, and began work in the Mississippi bottoms near Memphis. Work continued around Reelfoot Lake, on the Cumberland Plateau, and in the high mountains along the western border of the State, terminating on July 15 for the summer. In mid-September the party left for the field again, Mr. Lingebach being replaced by Henry R. Schaefer. The first collections were made on Roan Mountain, one of the highest mountains in the Eastern United States, with a summer temperature reputed to be the coldest for the entire Southeast in the summer season. Following

this, collections were made in the Clinch Mountains, and then the party again visited the area about Reelfoot Lake to follow the fall migration in that region. After further investigations in the central and southern part of the State, they returned to Washington the middle of November. The excellent collections of birds and mammals secured will form the basis of reports similar to those prepared for the work in West Virginia of last year. The work was carried on under the W. L. Abbott fund.

During October and November Dr. Alexander Wetmore, Assistant Secretary, traveled in northwestern Venezuela to make studies of the birds through arrangements perfected under the friendly cooperation of the American Minister, the Hon. Meredith Nicholson, and the gracious assistance of Dr. E. Gil Borges, Ministro de Relaciones Exteriores of Venezuela. In this work a survey was made of the bird life along a line extending from Ocumare de la Costa on the sea coast through the mountain range of the Cordillera de la Costa to Maracay and from there to the northern Llanos, in the vicinity of El Sombrero. In addition to securing an important collection of specimens, Dr. Wetmore made many observations on birds in life.

Capt. Robert A. Bartlett again visited the western coast of Greenland during the summer of 1937 on his schooner *Morrissey* and secured important gatherings of marine animals that were presented to the National Museum. Collections were made from Cape York north by way of Northumberland and Hakluyt Island, to Smith Sound.

Dr. D. C. Graham continued his collecting work in western China, forwarding many specimens of insects and of birds and other vertebrates.

Geology.—Dr. Charles E. Resser, curator of stratigraphic paleontology, studied Cambrian rocks on the flanks of the Adirondack Mountains in New York and Vermont and along the St. Lawrence River in Quebec, making investigations in Pennsylvania en route. In addition to collecting invertebrate fossils he was occupied in checking the relations of the various strata examined in connection with his work in the laboratory.

Dr. G. Arthur Cooper, assistant curator of stratigraphic paleontology, accompanied by P. E. Cloud, returned early in the year from a month's investigations of the Devonian of Michigan. In the latter half of September Dr. Cooper and Dr. Josiah Bridge visited the Champlain Valley to study the Chazyan rocks, both trips yielding excellent fossils. Dr. Cooper made a third trip in August, in company with Dr. Bradford Willard, of the Pennsylvania Topographic and Geologic Survey, to study the Tully formation along the Allegheny Front and from Lock Haven to the Schuylkill Valley.

E. P. Henderson was abroad from early in May until October 1937. Two months were occupied in attendance at the Seventeenth International Geological Congress at Moscow, in visiting important museums, and in collecting minerals in the Kola Peninsula and the Ural Mountains. The remaining time was occupied in Ceylon studying the gem deposits of that island, and in Japan in visiting mineralogical institutions and dealers from whom interesting specimens were obtained. Important mineralogical and geological collections were made, but the more important results are the contacts and exchanges, either made or initiated, by which a large quantity of Russian, Norwegian, Swedish, Scottish, and Japanese material will be received.

As the field expedition of 1937 under C. W. Gilmore, curator of vertebrate paleontology, extended well into the present fiscal year, but brief mention was made of it in last year's report. This expedition in the Upper Cretaceous of the North Horn area in central Utah, and in the Triassic of the Petrified Forest region of Arizona, met with most gratifying results. The Utah area was a virgin field so far as professional collecting was concerned, and the results obtained fully justified the venture. A good beginning was made in the development of a fauna for the North Horn formation of the Upper Cretaceous, and a small collection of mammalian remains indicated for the first time the presence of Paleocene strata in this geologic section. The finding of a large sauropod dinosaur skeleton in association with Upper Cretaceous dinosaur remains is a discovery of much interest and fully establishes the fact that this group of reptiles in North America lived into the Upper Cretaceous. Most of the specimens obtained are new to science. From the Triassic of Arizona important phytosaurian and amphibian remains were collected that go far in filling gaps in our permanent collections. The collections obtained filled 13 large cases having a combined weight of nearly 3 tons. George F. Sternberg, as in previous seasons, rendered efficient assistance, and George B. Pearce ably assisted as field assistant.

In May, Dr. C. L. Gazin, assistant curator of vertebrate paleontology, left Washington to head an expedition that will continue the explorations in central Utah so auspiciously begun last season. This will be followed by work in the Upper Eocene deposits of the Uinta Basin.

MISCELLANEOUS

Visitors.—Since the year 1932–33, when a low point was reached presumably as a result of unfavorable economic conditions, the number of visitors to the various Museum buildings has steadily mounted.

This year there were 119,638 more visitors than last, bringing the total up to 2,408,170, which is our greatest annual attendance to date. The attendance in the four Museum buildings was recorded as follows: Smithsonian Building, 371,770; Arts and Industries Building, 1,094,254; Natural History Building, 750,307; Aircraft Building, 191,839.

Publications and printing.—The sum of $21,000 was available during the year for the publication of the Museum annual report, bulletins, and Proceedings. Twenty-six publications were issued—the annual report, 1 volume of Proceedings completed, 5 bulletins, and 19 separate Proceedings papers. These aggregated 1,640 octavo pages and 242 plates, an increase of 36 pages and 107 plates over last year. The five bulletins issued were as follows: No. 100, volume 6, part 9, The Tree Snails of the Genus *Cochlostyla* of Mindoro Province, Philippine Islands, by Dr. Paul Bartsch; No. 166, The Oxystomatous and Allied Crabs of America, by Dr. Mary J. Rathbun; No. 168, Nearctic Collembola, or Springtails, of the Family Isotomidae, by the late Dr. Justus W. Folsom; No. 169, The Fort Union of the Crazy Mountain Field, Montana, and Its Mammalian Fauna, by Dr. George Gaylord Simpson; and No. 171, The Pleistocene Vertebrate Fauna from Cumberland Cave, Maryland, by the late Dr. James W. Gidley and Dr. C. Lewis Gazin.

Volumes and separates distributed during the year to libraries and individuals throughout the world aggregated 57,761.

Assistance from work relief agencies.—The Works Progress Administration of the District of Columbia continued the assignment of relief workers to Museum offices, and during the course of the year the number of such workers increased from 88 to 167. The work performed totaled 130,205 man-hours, and embraced such tasks as checking, labeling, and repairing library material; preparing drawings and photographs; typing notes and records; model making and repair; preparing, mounting, cataloging, numbering, and checking specimens; labeling and drafting; translating; and assisting with plaster casts.

Special exhibitions.—Seventeen special exhibitions were held during the year under the auspices of various educational, scientific, and governmental agencies. The division of graphic arts featured 17 special exhibits—8 in graphic arts and 9 in photography.

CHANGES IN ORGANIZATION AND STAFF

During the year there were few changes in the scientific staff. In the Department of Anthropology, Frank M. Setzler was appointed head curator on July 1, 1937, and Harry B. Collins, Jr., was advanced to associate curator, Division of Ethnology, on February 17, 1938. In

the Department of Biology, Dr. Leonard P. Schultz was made curator of the Division of Fishes on January 16, 1938, and H. Harold Shamel was advanced to senior scientific aid in the Division of Mammals on September 3, 1937. In the Department of Geology, Bertel O. Reberholt, by reallocation was advanced to senior scientific aid in the Division of Physical and Chemical Geology, November 1, 1937. William E. Moran was appointed junior scientific aid in the Division of Vertebrate Paleontology on June 16, 1938. In the Department of Arts and Industries, Kenneth M. Perry was appointed assistant exhibits worker in the Division of Mechanical Technology, on October 16, 1937.

On January 1, 1938, Norman H. Boss, chief preparator, Division of Invertebrate Paleontology, returned to duty from detail to the Greater Texas and Pan American Exposition at Dallas, where he was assigned as exhibit supervisor for the Smithsonian Institution.

The Museum lost through death during the year four employees: Arthur J. Poole, scientific aid in the Division of Mammals, on July 3, 1937, after 22 years 7 months of service; Daniel Clark, skilled laborer, on August 23, 1937, after 28 years of service; Jacob Willy, lieutenant of guard, on January 25, 1938, with 16 years of service; and William Robinson, laborer, on May 14, 1938, with 20 years of service. From the honorary staff the Museum lost through death Dr. Maurice C. Hall, honorary custodian of helminthological collections, on May 2, 1938.

Respectfully submitted.

Alexander Wetmore, *Assistant Secretary.*

Dr. Charles G. Abbot,
Secretary, Smithsonian Institution.

APPENDIX 2

REPORT ON THE NATIONAL GALLERY OF ART

Sir: Pursuant to the provisions of section 5 (b) of Public Resolution No. 14, Seventy-fifth Congress, approved March 24, 1937, I have the honor, on behalf of the trustees of the National Gallery of Art, to submit the first annual report of the Board, covering the fiscal year ended June 30, 1938, on its operations under the aforementioned joint resolution.

Under the joint resolution of Congress it appropriated to the Smithsonian Institution the area bounded by Seventh Street, Constitution Avenue, Fourth Street and North Mall Drive (now Madison Drive) Northwest, in the District of Columbia, as a site for a National Gallery of Art; authorized the Smithsonian Institution to permit The A. W. Mellon Educational and Charitable Trust, a public, religious, educational, and charitable trust, established by the late Hon. Andrew W. Mellon, of Pittsburgh, Pa., to construct thereon a building to be designated the "National Gallery of Art"; and created, in the Smithsonian Institution, a bureau to be directed by a board to be known as the "Trustees of the National Gallery of Art," charged with the maintenance and administration of the National Gallery of Art. This act provides that the board be comprised of the Chief Justice of the United States, the Secretary of State, the Secretary of the Treasury, and the Secretary of the Smithsonian Institution, ex-officio, and five general trustees. The general trustees first taking office were to be chosen by the Board of Regents of the Smithsonian Institution; and their successors are to be chosen by the majority vote of the general trustees.

On June 24, 1937, the Board of Regents of the Smithsonian Institution appointed the following as general trustees of the National Gallery of Art:

Donald D. Shepard, for the term expiring July 1, 1939;
S. Parker Gilbert, for the term expiring July 1, 1941;
Duncan Phillips, for the term expiring July 1, 1943;
David K. E. Bruce, for the term expiring July 1, 1945;
Andrew W. Mellon, for the term expiring July 1, 1947.

The Trustees deeply regret to report that Andrew W. Mellon, the donor of the great art collection which has been deeded to the Gallery

as well as the funds for the erection of the the gallery building to house the collection, died on August 26, 1937; also that S. Parker Gilbert, one of the original general trustees, died on February 23, 1938. On March 9, 1938, the three surviving general trustees, at a meeting duly held at Washington, D. C., elected Paul Mellon to serve the unexpired term of his father, the late Andrew W. Mellon, and Ferdinand Lammot Belin was elected to serve the unexpired term of the late S. Parker Gilbert.

On March 9, 1938, an organization meeting of the Trustees was held in the Regents Room of the Smithsonian Institution and, after full consideration by the Trustees, a draft of bylaws submitted at the meeting was adopted as the bylaws of the Trustees of the National Gallery of Art.

The bylaws provide that the executive officers shall consist of the chairman of the Board, president, vice president, secretary, treasurer, director, administrator, assistant director, chief curator, and such other executive officers as the Board shall determine. The Chief Justice of the United States, ex-officio, is the chairman of the Board.

At this meeting it was determined that the regular annual meeting of the Board shall be held on the second Monday in February of each year, at 9:30 a. m.

Also the Trustees elected the following executive officers:

Paul Mellon, president;
David K. E. Bruce, vice president;
Donald D. Shepard, secretary;
Donald D. Shepard, treasurer;
David E. Finley, director.

The officers elected stated they would serve without compensation for the time being. It was decided by the Trustees that the matter of their later compensation, if any, should be considered at a subsequent meeting of the Board. The following Trustees were elected as members of the three standing committees, provided for in the bylaws:

EXECUTIVE COMMITTEE

Chief Justice of the United States;
Dr. C. G. Abbot;
Paul Mellon;
David K. E. Bruce;
Donald D. Shepard.

ACQUISITIONS COMMITTEE

Paul Mellon;
David K. E. Bruce;
David E. Finley;
Duncan Phillips;
Ferdinand Lammot Belin.

FINANCE COMMITTEE

Hon. Henry Morgenthau, Jr.;
Hon. Cordell Hull;
Paul Mellon;
David K. E. Bruce;
Ferdinand Lammot Belin.

Appropriate resolutions were passed relating to the reproduction by photographs, or otherwise, of works of art controlled by the Board, the use of such reproductions, the viewing and care of the collection. The Board directed the treasurer, under the supervision and subject to the approval of the finance committee, to cause to be established an appropriate accounting system, including provisions for the keeping of necessary books and records, so that the works of art now under the control of the Board and all funds, securities, and works of art and other properties of whatsoever character belonging to or under the control of the Board and of such additions and receipts thereto and disposition, withdrawals and disbursements therefrom, may be properly recorded.

Under the trust indenture of June 24, 1937, between the Trustees of The A. W. Mellon Educational and Charitable Trust, the Smithsonian Institution, and the Trustees of the National Gallery of Art, the Smithsonian Institution received title to the works of art given by The A. W. Mellon Educational and Charitable Trust, upon the understanding that pending completion of the Gallery, the donor would retain custody of the gift, at its expense, and that upon delivery, the gift would form part of the permanent collection in the custody of the Trustees of the National Gallery of Art. Pursuant to its offer, accepted by the Trustees of the National Gallery of Art at its meeting on March 9, 1938, The A. W. Mellon Educational and Charitable Trust has defrayed the current administrative expenses of the Gallery, as well as the expense of storage and the care of the collection pending the completion of the National Gallery of Art. During the 18 months ended June 30, 1938, the total of such administrative expenses and expenses of storage amounted to about \$150,000 principally accounted for by insurance premiums on policies expiring in 1940. The collection is now stored in the Corcoran Gallery of Art. The collection is in excellent condition and is being well protected and cared for. The current expenses for the custody of the collection are at the rate of approximately \$12,000 per annum. Such expenses are being paid by The A. W. Mellon Educational and Charitable Trust and, of course, are not recorded on the books of account of the National Gallery of Art.

Pursuant to the joint resolution and the trust indenture of June 24, 1937, The A. W. Mellon Educational and Charitable Trust is also proceeding, at its expense, with the construction of the National

Gallery of Art on the site set aside for it by the Congress. At June 30, 1938, $1,796,147.29 had been expended upon construction, and the foundations of the Gallery were substantially completed. We are advised that if no unusual delay, occasioned by conditions beyond the contractor's control, is encountered, the Gallery will be completed by September 1940, and sufficient Gallery rooms will be available for the display of the works of art by November 1940. We are advised that the Trustees of The A. W. Mellon Educational and Charitable Trust estimate that the total cost of the building will exceed $15,000,000. Recording of such expenditures in the books of account of the National Gallery of Art will be deferred until completion of the construction of the Gallery.

Section 4 (b) of the joint resolution authorizes the Trustees to accept and administer gifts of money or securities. In a letter dated February 16, 1937, from the late Hon. A. W. Mellon to Hon. Kent E. Keller, chairman of the Committee on the Library of the House of Representatives, Mr. Mellon stated that the endowment fund for the Gallery, as proposed in his letter to the President of the United States, had been fixed at an amount of $5,000,000. It is understood that this fund is expected to be received by the Trustees of the National Gallery of Art from the Trustees of The A. W. Mellon Educational and Charitable Trust, at or about the time of the completion of the National Gallery of Art.

There were no additions to the collection of the National Gallery of Art during the year. However, the Gallery has received a number of offers of gifts of works of art. Such offers were referred to the acquisitions committee for consideration. Also there were no loans of works of art under the control of the Trustees of the Gallery during the year. No appropriation was made by Congress for the National Gallery of Art during the fiscal year ended June 30, 1938, and no public or private funds received or disbursed during the year.

Pursuant to instructions, Price, Waterhouse & Co., a nationally known firm of public accountants, has made an examination of the accounting records of the National Gallery of Art, the accounting system having been installed upon the recommendation of that firm. Price, Waterhouse & Co. report that, based upon its examination, the books of account of the National Gallery of Art fairly present, in accordance with the accepted principles of accounting, the position of the National Gallery of Art at June 30, 1938. Copy of the certificate of Price, Waterhouse & Co., dated August 26, 1938, is attached hereto and made a part of this report. It should be noted that the only entry on the books of account of the National Gallery of Art, as of June 30, 1938, was the opening journal entry of June

24, 1937, recording its acquisition of the collection of works of art, there being no other transactions to June 30, 1938, which should be recorded in the books of account. The gift of June 24, 1937, was recorded on the books of account at $31,303,162.31, representing, according to available information, the cost to the last person to acquire the works of art by purchase. Of this amount $19,893,162.31 represented purchases of works of art by the late Hon. Andrew W. Mellon, and $11,410,000 represented purchases by The A. W. Mellon Educational and Charitable Trust. A list of the works of art which were the subject of the gift of June 24, 1937, is attached to this report. The certificate of Price, Waterhouse & Co. states that the receipt of title to this gift was recorded properly in the Gallery's books by the opening journal entry.

The certificate of Price, Waterhouse & Co. follows:

AUGUST 26, 1938.

Mr. DONALD D. SHEPARD,
Treasurer, National Gallery of Art,
716 Jackson Place NW., Washington, D. C.

DEAR SIR: Pursuant to your instructions, we have made an examination of the accounting records of the National Gallery of Art and other documentary evidence, and have obtained information and explanations from its officers. The only entry in its books of account as at June 30, 1938, was the opening journal entry dated June 24, 1937, recording its acquisition of works of art; our examination disclosed no other transactions to June 30, 1938, which should be recorded in the books of account.

Pursuant to joint resolution of Congress, approved March 24, 1937, and trust indenture dated June 24, 1937, The A. W. Mellon Educational and Charitable Trust, at its expense, is proceeding with construction of the National Gallery of Art. The recording of such expenditures in the books of account of the National Gallery of Art is deferred until completion of construction.

By the aforementioned trust indenture title was acquired to the works of art given by The A. W. Mellon Educational and Charitable Trust. Pending construction of the Gallery, these works of art remain in the custody of the donor to be cared for at its expense. This gift was recorded in the books of account at $31,303,162.31, representing, according to available information, the cost to the last person to acquire the works of art by purchase. Of this amount, $19,893,162.31 represented purchases by Mr. A. W. Mellon and $11,410,000.00 represented purchases by The A. W. Mellon Educational and Charitable Trust. The receipt of title to this gift was recorded properly in the Gallery's books by the opening journal entry previously referred to.

An endowment fund of $5,000,000 is expected to be received from The A. W. Mellon Educational and Charitable Trust at about the time of completion of the Gallery.

In our opinion, based upon our examination, the books of account fairly present, in accordance with accepted principles of accounting, the position of the National Gallery of Art at June 30, 1938.

Yours very truly,

(Signed) PRICE, WATERHOUSE & CO.

LIST OF WORKS OF ART DEEDED TO NATIONAL GALLERY OF ART JUNE 24, 1937

Name of artist	Title of picture
Fra Angelico	The Madonna and Child.
Antonello da Messina	Do.
Do	Portrait of a Member of the Contarini Family.
Giovanni Bellini	The Flight Into Egypt.
Do	Portrait of Young Man in Red Coat.
Botticelli	Adoration of the Magi.
Do	The Madonna and Child.
Do	Portrait of a Young Man in Brown Coat and Red Hat.
Do	Portrait of a Young Man in Mauve Coat and Red Hat.
Byzantine Master (circa 1200)	The Madonna and Child.
Castagno, Andrea del	Portrait of a Young Man.
Chardin	La Maitresse d'École.
Do	The House of Cards.
Christus, Petrus	The Nativity.
Cimabue	Christ Between St. Peter and St. James (a triptych).
Conegliano, Cima da	The Madonna and Child With St. John the Baptist and St. Anthony.
Constable	A View of Salisbury Cathedral.
Cuyp	Herdsman Tending Cattle.
Gerard David	Rest During the Flight Into Egypt.
Duccio di Buoninsegna	The Nativity With the Prophets Isaiah and Ezekiel.
Dürer	Portrait of a Man in Dark Cloak With Fur Collar.
Gainsborough	Portrait of Georgiana, Duchess of Devonshire.
Do	Portrait of George IV When Prince of Wales.
Do	Landscape With a Bridge.
Do	Portrait of Miss Catherine Tatton.
Do	Portrait of Mrs. John Taylor.
Do	Portrait of Mrs. Richard Brinsley Sheridan.
School of Giotto	Large Panel Representing St. Paul.
Giovanni di Paolo	The Adoration of the Magi.
Goya	Portrait of Senora Sebasa Garcia.
Do	Portrait of the Marquesa de Pontejos.
Do	Portrait of King Carlos IV of Spain.
Do	Portrait of Queen Maria Luisa of Spain.
El Greco	San Ildefonso of Toledo.
Do	St. Martin and Beggar.
Frans Hals	Portrait of Balthasar Coymans.
Do	Portrait of an Officer With a Red Sash.
Do	Portrait of Nicholas Berghem.
Do	Portrait of an Old Lady Seated.
Do	Portrait of a Young Man.
Hobbema	La Ferme au Soleil.
Do	The Holford Landscape.
Do	Village Scene.
Hans Holbein (The Younger)	Portrait of Sir Bryan Tuke.
Do	Portrait of Edward VI as a Boy.
Pieter de Hoogh	A Dutch Courtyard.
Hoppner	The Frankland Sisters.
Lancret, Nicholas	The Dancer, La Camargo.
Lawrence	Lady Templetown and Child.

Name of artist	Title of picture
Lippi, Filippino	The Madonna and Child With Angel.
Luini	Portrait of a Lady.
Maes, Nicholas	Portrait of an Old Lady at Prayer.
Mantegna	St. Jerome in the Wilderness.
Masaccio	Profile Portrait of a Young Man.
Do	The Madonna of Humility.
Masolino da Panicale	The Annunciation.
Matteo di Giovanni	The Adoration of the Magi.
Do	The Virgin and Child With Angels.
Memling	Portrait of a Man With an Arrow.
Do	The Madonna and Child With Angels.
Lippo Memmi	The Madonna and Child.
Metsu	The Intruder.
Master Michael	Portrait of a Donor (A Knight of the Order of Calatrava).
Moro	Self-Portrait With his Dog.
Neroccio dei Landi	The Vestal Claudia Quinta.
Allegretto Nuzi da Fabriano	The Virgin Enthroned (a triptych).
Perugino	Crucifixion With the Virgin, SS. John, Magdalen, and Jerome (a triptych).
Pisanello	A Portrait of a Lady Presumed to be Isotta degli Atti.
Raeburn	Portrait of Colonel Francis James Scott.
Do	Portrait of John Tait and His Grandson.
Do	Portrait of Miss Eleanor Urquhart.
Raphael	The Madonna and Child (known as the Niccolini or Cowper Madonna).
Do	Madonna of the House of Alba.
Do	St. George and the Dragon.
Rembrandt	Portrait of an Old Lady Seated in an Armchair.
Do	Lucretia.
Do	Portrait of Himself, Dated 1659.
Do	Portrait of a Polish Nobleman.
Do	Portrait of a Young Woman Holding a Pink.
Do	Joseph and Potiphar's Wife.
Do	Portrait of a Girl With a Broom.
Do	Portrait of a Young Man at Table.
Reynolds	Portrait of Lady Betty Delmé and Her Children.
Do	Portrait of Lady Caroline Howard.
Do	Portrait of Lady Betty Compton.
Romney	Portrait of Lady Broughton.
Do	Portrait of Mrs. Davenport.
Do	Portrait of Miss Willoughby.
Rubens	Portrait of Isabella Brant, First Wife of the Artist.
Do	Portrait of Suzanne Fourment and Daughter.
Starnina	The Virgin Enthroned with SS. Mark, Benedict, Bernard and Catherine (a triptych).
Terborch	A Gentleman Greeting a Lady.
Titian	The Madonna and Child With the Infant St. John in Landscape.
Do	Portrait of a Man (Andrea dei Franceschi).
Do	The Toilet of Venus.
Turner	Mortlake Terrace (Summer Evening).

Name of artist	Title of picture
Turner	Approach to Venice.
Rogier van der Weyden	Portrait of a Lady in a White Veil.
Do	The Risen Saviour Appearing to His Mother.
Van Dyck	Portrait of Lord Phillip Wharton.
Do	Portrait of William II of Nassau and Orange
Do	Portrait of the Marchesa Balbi.
Van Eyck	The Annunciation.
Velasquez	Portrait of Pope Innocent X.
Do	Portrait of a Young Man.
Do	Woman Sewing.
Vermeer, Jan	Girl With a Red Hat.
Do	The Lace Maker.
Do	Smiling Girl.
Veneziano, Domenico	Portrait of a Member of the Olivieri Family
Veronese	The Finding of Moses.

SCULPTURES

Name of sculptor	Title of sculpture
Agostino di Duccio	Madonna and Child (marble bas relief).
Amadeo	2 marble plaques with bust portraits in relief of Lodovico Sforza and Gian Galeazzo Sforza.
Giovanni da Bologna	A bronze statue representing Mercury.
Donatello	Bust of Youthful St. John the Baptist (painted terra cotta).
Do	Painted terra cotta statuette representing Madonna and Child.
Fiesole, Mino da	2 marble plaques representing Charity and Faith.
Do	Madonna and Child (marble relief).
Laurana	White marble bust of a Princess of Aragon.
Luca della Robbia	The Madonna and Child (tondo) (enameled terra cotta relief).
Do	The Madonna and Child (upright) (enameled terra cotta relief).
Do	The Virgin Adoring the Child (unglazed terra cotta).
Rossellino, Antonio	The Madonna and Child (terra cotta).
Sansovino, Jacopo	Life size statue in bronze representing Bacchus and a Young Faun.
Do	Life size statue in bronze representing Venus Anadyomene.
Desiderio da Settignano	Bust of Giovanna Degli Albizzi.
Do	Christ and St. John the Baptist in Their Childhood (marble relief).
Do	Life size marble bust of boy.
Do	The Madonna and Child (marble relief).
Verrocchio	Statuette of Boy Poised on Globe (terra cotta).
Do	Bust of Giovanna Tornabuoni (terra cotta).
Do	Bust of Giuliano de Medici (terra cotta).

Respectfully submitted.

PAUL MELLON,
President, National Gallery of Art.

DR. C. G. ABBOT,
Secretary, Smithsonian Institution.

APPENDIX 3

REPORT ON THE NATIONAL COLLECTION OF FINE ARTS

Sir: I have the honor to submit the following report on the activities of the National Collection of Fine Arts for the fiscal year ended June 30, 1938:

The name "National Collection of Fine Arts," which has now been in existence for a year and a quarter, is perhaps still not well understood. I wish to call attention, therefore, to the fact that the National Collection of Fine Arts is the name now used to designate the art collections administered by the Smithsonian Institution, with the exception of those which The Andrew W. Mellon Charitable and Educational Foundation will place in the building now under construction which will be known as the "National Gallery of Art."

Congress, late in the last session, passed a bill authorizing the Smithsonian Institution to obtain plans for a building to be known as the "Smithsonian Gallery of Art," and authorizing the President to select a site for it on the Mall between Fourth and Fourteenth Streets. This new building will house the art collections under the charge of the Smithsonian Institution which are not to be in the National Gallery of Art. The bill also authorized the soliciting of funds for the construction of the Smithsonian Gallery of Art, and for an endowment to be used in purchasing works of art.

There were 484 visitors to the main office during the year. Many submitted art objects for examination and identification, and others sought general information.

APPROPRIATIONS

For the administration of the National Collection of Fine Arts by the Smithsonian Institution, including compensation of necessary employees, purchase of books of reference and periodicals, traveling expenses, uniforms for guards, and necessary incidental expenses, $34,275 was appropriated. This amount was reduced $750, bringing it to $33,525, of which $16,542 was expended for the care and maintenance of the Freer Gallery of Art, a unit of the National Collection of Fine Arts. The balance of $16,983 was spent for the care and upkeep of the National Collection of Fine Arts, nearly all of this sum being required for the payment of salaries, traveling expenses, books, periodicals, and other necessary disbursements for the care of the col-

lections, so that only a very small sum was available for improvements in the exhibition halls.

THE NATIONAL GALLERY OF ART COMMISSION

The seventeenth annual meeting of the National Gallery of Art Commission was held on December 7, 1937. The members met at 10:30 at the rooms of the National Collection of Fine Arts, in the Natural History Building, where, as the advisory committee on the acceptance of works of art which had been submitted during the year, they accepted the following:

A wood gravure of "Rockwell Studio," by Macowin Tuttle. Gift of Mrs. Mary E. Lathrop, Rockford, Ill.

The members then proceeded to the Smithsonian Building, where the annual meeting was called to order by the chairman, Mr. Borie. The members present were: Charles L. Borie, Jr., chairman; Frank Jewett Mather, Jr., vice chairman; Dr. Charles G. Abbot (ex officio), secretary; and Herbert Adams, Gifford Beal, George H. Edgell, James E. Fraser, John E. Lodge, Paul Manship, George B. McClellan, Edward W. Redfield, and Mahonri M. Young. Ruel P. Tolman, curator of the Division of Graphic Arts in the United States National Museum and acting director of the National Collection of Fine Arts, was also present.

The following resolutions on the death of Mr. Andrew W. Mellon were submitted and adopted, and Secretary Abbot was requested to convey a copy to Mr. Mellon's family:

Whereas the National Gallery of Art Commission has learned of the death, on August 26, 1937, of Andrew W. Mellon, a member of this Commission since 1934; therefore be it

Resolved, That the Commission records its sincere sorrow at the passing of Mr. Mellon, who devoted many years of his long life to assembling an exceptionally fine collection of paintings and sculpture. With patriotic generosity he gave in 1937 this outstanding collection of masterpieces to the Smithsonian Institution for the United States with the hope that Washington would become the art center of the world. At the same time he provided funds for a monumental marble building to be known as the National Gallery of Art, and arranged for an endowment, proposed to be $5,000,000. No other gift of art has ever equalled this one.

Mr. Mellon had a deep interest also in the great building program of the Government, and did much, as Secretary of the Treasury, to promote it. Although he lived to a great age, the Commission deeply deplores the untimely death of Mr. Mellon before he could see and enjoy the full fruition of his work and his beneficence.

Resolved, That these resolutions be spread upon the records of the Commission and that the Secretary be requested to convey a copy to the family of Mr. Mellon.

The Commission recommended to the Board of Regents the name of David E. Finley to fill the vacancy caused by the death of Mr. Mellon.

It also recommended to the Board of Regents the reelection for the succeeding term of 4 years of the following members: Charles L. Borie, Jr., Frederick P. Keppel, George B. McClellan, and Mahonri Young.

The following officers were reelected for the ensuing year: Charles L. Borie, Jr., chairman; Frank Jewett Mather, Jr., vice chairman; and Dr. Charles G. Abbot, secretary; as well as the members of the executive committee—Charles Moore, Herbert Adams, and George B. McClellan (Charles L. Borie, Jr., as chairman of the Commission, and Dr. Charles G. Abbot, as secretary of the Commission, are ex-officio members of the executive committee).

The advisability of recommending to the Board of Regents a change in the name of the Commission was considered and the following minute was agreed upon:

> Owing to the appropriation of the name "National Gallery of Art" to the gallery being erected to contain the gift of Mr. Mellon, the Commission recommends to the Board of Regents of the Smithsonian Institution that its name be changed from "National Gallery of Art Commission" to "Smithsonian Gallery of Art Commission." [1]

The question of a building for the Smithsonian Gallery of Art, to contain the National Collection of Fine Arts, and of a site for such a gallery, was discussed, and Dr. Abbot, Messrs. Borie, McClellan, Moore, and Keppel (with the addition of Mr. Edgell in case Mr. Keppel was not available) were appointed to consider the two pending Congressional resolutions on this subject (S. J. Res. 99, by Senator Walsh, and H. J. Res. 280, by Representative Keller).

It was decided that future annual meetings should be held on the first Tuesday in December of each year.

THE CATHERINE WALDEN MYER FUND

Five miniatures were acquired from the fund established through the bequest of the late Catherine Walden Myer, as follows:

"Portrait of Henry Trescot," painted in 1822 by Charles Fraser (1782–1860); from Mrs. Grace M. Trescot, Washington, D. C.

"Portrait of Elizabeth Knapp," by James Peale, 1802; from H. D. Miller, Baltimore, Md.

"Portrait of Charles Frederick Vogel," attributed to Rembrandt Peale; from Mrs. Margaret G. Mack Harrison, Raleigh Court, University, Va., through Miss Leila Mechlin.

"Portrait of Dr. George Ackerly," by Henry Inman (1801–1846): from Mrs. Josephine C. Gager, Washington, D. C.

"Portrait of Napoleon III," signed "F. de Fournier, Paris, 52;" from Miss Marion Lane, Washington, D. C.

[1] The Board of Regents, after careful consideration, decided that the name should be "Smithsonian Art Commission."

LOANS ACCEPTED

Two portraits in pastel, by James Sharples (c. 1751–1811) of General James Miles Hughes (1756–1802), original member of the Society of the Cincinnati, and Mrs. James Miles Hughes, his wife, were lent by Madame Florian Vurpillot, Washington, D. C.

LOANS MADE

"The Cup of Death," by Elihu Vedder, was lent to The American Academy of Arts and Letters, New York, N. Y., for a Memorial Exhibition planned for the period November 18, 1937, to May 1, 1938, but the picture was returned April 12, 1938.

"Portrait of Thomas Hopkinson," by Robert Feke, and "Portrait of Mary Hopkinson," by Benjamin West, from the George Buchanan Coale (1819–87) Collection, Baltimore, were lent to the United States Constitution Sesquicentennial Commission for a historical loan exhibition of authentic portraits of the Signers of the Declaration of Independence and the Deputies to the Constitutional Convention, held at the Corcoran Gallery of Art from November 27, 1937, to March 1, 1938. (Returned March 3, 1938.)

"Cliffs of the Upper Colorado River, Wyoming Territory," by Thomas Moran, was lent to the Whitney Museum of American Art, New York, N. Y., for "A Century of American Landscape Painting," which was held from January 19 to February 27, 1938.

At the conclusion of the above exhibition, the painting "Cliffs of the Upper Colorado River, Wyoming Territory," by Thomas Moran, was forwarded to The Springfield Museum of Fine Arts, Springfield, Mass., for "A Century of American Landscape Painting 1800–1900" which was held from March 8 to 28, 1938. (Returned April 2, 1938.)

The following 20 paintings were lent to the Howard University Gallery of Art for an exhibition of American paintings from May 2 to June 13, 1938:

At Nature's Mirror, by Ralph A. Blakelock.
Caresse Enfantine, by Mary Cassatt.
Portrait Sketch of Walter Shirlaw, by Frank Duveneck.
A Pool in the Forest, by Benjamin R. Fitz.
Birch-Clad Hills, by Ben Foster.
Ideal Head, by George Fuller.
Portrait of Mrs. Albert J. Myer, by George P. A. Healy.
The Visit of the Mistress, by Winslow Homer.
Friendly Neighbors, by Alfred C. Howland.
Georgia Pines, by George Innes.
Evening on the Seine, by Homer D. Martin.
Great Silas at Night, by Robert C. Minor.
Cliffs of the Upper Colorado River, Wyoming Territory, by Thomas Moran.

The Path to the Village, by J. Francis Murphy.
Moonlight, by Albert P. Ryder.
Late Afternoon (The Alcazar, Segovia), by Wells M. Sawyer.
Portrait of Joseph Head, by Gilbert Stuart.
Edwin M. Stanton, by Henry Ulke.
Roosevelt Haunts, Early Autumn, by Emile Walters.
Autumn at Arkville, by Alexander H. Wyant.

(Returned June 14, 1938.)

LOANS RETURNED

Three paintings, "Madonna with Halo of Stars," "Adoration of the Christ Child," and "The Christ Child with Cross and Torch," by undetermined artists, lent to the Public Library of the District of Columbia, December 16, 1936, were returned September 27, 1937.

A bronze statue of Lincoln, by Augustus Saint Gaudens, lent, with the consent of the owners, the Estate of Mrs. John Hay, to the Great Lakes Exposition, Cleveland, Ohio, was returned October 5, 1937.

WITHDRAWALS BY OWNERS

An oil painting entitled "The Immaculate Conception with the Mirror," by Murillo, lent in 1930; withdrawn by the owner, DeWitt V. Hutchings, Riverside, Calif., on November 19, 1937.

Two portraits, "Miss Jessie Jay Burge," by Abbott H. Thayer, and "Miss Elizabeth Ellery Burge," by Thomas Mathewson, lent in 1922; withdrawn by the owners, the Misses Marie Louise and Jessie Jay Burge, Wickford, R. I., on March 3, 1938.

Portrait of Abraham Lincoln, by M. S. Nachtrieb, lent in 1921; withdrawn by the owner, Anton Heitmuller, Washington, D. C., on April 11, 1938.

One Sevres porcelain statuette, by Paul Dubois, entitled "Le Courage Militaire," lent in 1930; withdrawn by the owner, Hon. Hoffman Philip, Washington, D. C., on May 17, 1938.

"A Madonna," by Giovanni Battista Salvi (called Il Sassoferrato), lent in 1929; withdrawn by the owner, Mrs. Charles J. Fox, La Jolla, Calif., on May 31, 1938.

THE HENRY WARD RANGER FUND PURCHASES

The paintings purchased during the year by the Council of the National Academy of Design from the fund provided by the Henry Ward Ranger Bequest, which, under certain conditions, are prospective additions to our collections, and the names of the institutions to which they have been assigned, are as follows (these are the first purchases since April 1933):

Title	Artist	Date of purchase	Assignment
112. Medieval Art	Edwin H. Blashfield, N. A. (1848–1936).	December 1937.	William Rockhill Nelson Gallery of Art, Kansas City, Mo.
113. Fifteenth Century French Madonna and Child.	Harry W. Watrous, N. A.	do	Not assigned.
114. Boxholder No. 27	Francis Speight, A. N. A. (elect).	do	Trustees of the Wood Art Gallery, Montpelier, Vt.

THE NATIONAL COLLECTION OF FINE ARTS REFERENCE LIBRARY

The 795 publications accessioned during the year were obtained through purchase, transfer, gift, and exchange.

SPECIAL EXHIBITIONS

Six exhibitions were held as follows:

August 2 to 8, 1937.—A special exhibition of the art of Mexican school children, 262 items, sponsored by the Ministry of Education, Mexican Government, through Dr. L. S. Rowe, of the Pan American Union.

October 15 to 31, 1937.—Joint exhibition of the Twenty Women Painters and the Landscape Club, of Washington, D. C. Fifty-two paintings were exhibited by the Twenty Women Painters and 61 by the Landscape Club.

February 4 to 27, 1938.—A special exhibition of 74 water colors by William Spencer Bagdatopoulos.

April 6 to 29, 1938.—A special exhibition of 85 paintings, 20 framed and 41 unframed water colors, 34 etchings, and 33 pieces of sculpture from the National Collection of Fine Arts.

April 13 to May 7, 1938.—A special exhibition of three portraits by Henrique Medina, sponsored by Dr. João Antonio de Bianchi, Minister from Portugal.

June 3 to 30, 1938.—A special exhibition of 260 naval historical prints from the Eberstadt Collection, lent by the Naval Historical Foundation. (This exhibition was extended through August.)

PUBLICATIONS

TOLMAN, R. P. Report on the National Collection of Fine Arts for the year ending June 30, 1937. Appendix 2, Report of the Secretary of the Smithsonian Institution for the year ending June 30, 1937, pp. 35–42.

LODGE, J. E. Report of the Freer Gallery of Art for the year ending June 30, 1937. Appendix 3, Report of the Secretary of the Smithsonian Institution for the year ending June 30, 1937, pp. 43–47.

Respectfully submitted.

R. P. TOLMAN, *Acting Director.*

Dr. C. G. ABBOT,
Secretary, Smithsonian Institution.

APPENDIX 4

REPORT ON THE FREER GALLERY OF ART

SIR: I have the honor to submit the eighteenth annual report on the Freer Gallery of Art for the year ended June 30, 1938:

THE COLLECTIONS

Additions to the collections by purchase are as follows:

BRONZE

38.5. Chinese, Chou dynasty. A ceremonial vessel of the type *kuang*. White bronze with a smooth apple-green patina; traces of red earth adhesions. The decoration is delicately cut in low and incised relief. Inscriptions in vessel and cover. 0.235 by 0.310 by 0.112. (Illustrated.)

38.6. Chinese, Chou dynasty. A ceremonial vessel of the type *chih*. White bronze having a silvery-green patina, with areas of rough green; earthy adhesions. The decoration is in low relief. 0.190 by 0.089. (Illustrated.)

38.7 Chinese, fifth–third centuries, B. C. Period of the Warring States. A food-vessel; four animalistic knobs on the cover and mask-and-ring handles on the body. White bronze having a smooth gray-green patina, with areas of incrustation outside; a rough green *aerugo* inside. The decoration is inlaid with silver and turquoise. 0.148 by 0.222.

38.8. Chinese, T'ang dynasty. A mirror. The surface shows a lustrous gray patina with areas of green and black, and patches of earthy adhesions. The decoration consists of a dragon in clouds, executed in low relief. 0.212 (diameter).

GOLD

37.45. Chinese, Ch'ing, eighteenth century, period of Ch'ien Lung. A *ju-i* sceptre of gold filigree adorned with turquoise inlays. The designs of the latter include those of the "Eight Treasures." A silk tassel is attached through a turquoise bead. Length, 0.240 (exclusive of tassel). (Illustrated.)

JADE

38.16. Chinese, fifth–third centuries, B. C. Period of the Warring States. The figure of a female dancer, carved in translucent white nephrite; an eyelet for attachment. Height, 0.080.

MANUSCRIPT

37.46. Arabic (Persia), twelfth century. A bound volume of the *Qur'ān* (incomplete). The text is written on paper leaves in Persian *kūfī* script in black ink with diacritics in red and green, 10 lines on a page. Chapter titles, marginal marks, and verse-stops are illuminated. 0.314 by 0.202 (average leaf).

38.15. Arabic, fourteenth century. A paper leaf from a *Qur'ān*. Illuminated title-piece, marginal ornaments and verse-stops. The text is written in *naskhī* script in gold and blue, 11 lines on a page. 0.344 by 0.259.

PAINTING

38.4. Chinese, Sung period, thirteenth century. By Kung K'ai. Chung K'uei, the demon-queller, on his travels. Ink on paper. Signature and inscription by the artist; 22 other inscriptions; 138 seals plus one seal on the label. Makimono: 0.328 by 1.695.

38.9. Chinese, Yüan dynasty, A. D. 1362. By Ni Tsan (1301–1374). Landscape. Ink on paper. Signature, dated. Forty-five seals on the painting; two on the mount. Nine inscriptions. Makimono: 0.300 by 0.503.

38.17. Indian, Rājput, about 1600. Hanumān standing before Rāma and Sītā, enthroned and attended by Lakṣmaṇa. Opaque color and gold on paper. 0.163 by 0.245.

38.1. Persian (Mesopotamia), Baghdad school, A. D. 1222. By 'Abdallāh ibn al-Faḍl. Two physicians cutting a plant. In opaque colors and gold on paper. This leaf is from the well-known Arabic translation of the *Materia Medica* of Dioscorides; the text is written in *naskhī* script in brown ink with headings and punctuation in red. 0.330 by 0.249 (leaf).

38.2. Persian, early fourteenth century. An llustration from a *Manafi' al-Ḥayawān:* a deer and magpies. In transparent colors, black and slight gold on paper. Titles (*recto* and *verso*) are written in monumental *kūfī* script in blue; the text in a small *naskhī* hand in black and red. 0.260 by 0.200 (leaf).

38.3. Persian, Mongol school, fourteenth century. An illustration from a *Shāhnāmah* of Firdawsī: the bier of Iskandar (Alexander the Great). In colors, black and gold on paper. The title of the painting is written above it in gold *naskhī* script; the text in black *naskhī*. 0.408 by 0.298 (leaf). 0.250 by 0.280 (painting).

38.14. Persian, early Timurid period, Mongol school. Fourteenth century. Two women carrying a tray with cups and a spouted pot. Ink outline, with additions of gold, and transparent red, blue, and green, on paper. 0.195 by 0.158.

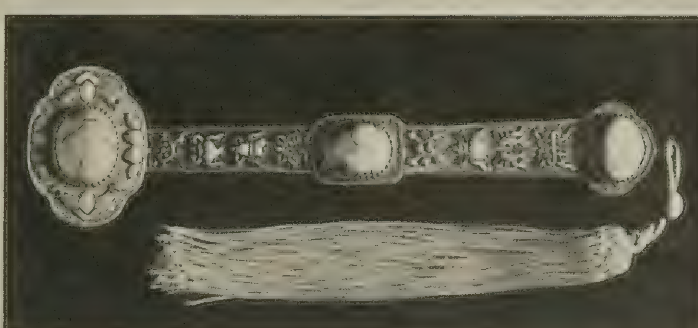
PORCELAIN

38.10. Chinese, eighteenth century, period of Ch'ien Lung (A. D. 1736–95). A vase. Hard, semitranslucent clay; brilliant gray-white glaze. Decorated with landscape designs painted in colored enamels over glaze. Inscription and three seals painted over glaze; a date-mark in underglaze blue under the foot. 0.244 by 0.132.

POTTERY

38.12. Persian, thirteenth century. Rhages (Raiy). A bowl (broken and repaired). Soft sandy, white clay; opaque white glaze (crazed); blue border outside, and blue wash over the foot. The decoration is painted in polychrome enamels and gold: inside, two seated figures; outside, a formal pattern. 0.088 by 0.230. (Illustrated.)

38.12



37.45

SOME RECENT ADDITIONS TO THE COLLECTION OF THE FREER GALLERY OF ART.

38.6

38.5

SOME RECENT ADDITIONS TO THE COLLECTION OF THE FREER GALLERY OF ART.

38.13. Persian, thirteenth century. Rhages (Raiy). A bowl. Soft, sandy, white clay; opaque grayish-white glaze (crazed and clouded). The decoration is painted in polychrome enamels, on both inner and outer surfaces, including a medallion under the foot. An auspicious inscription executed in *kūfī* script in white reserve on a blue ground. 0.086 by 0.205.

STONE SCULPTURE

38.11. Egyptian, Old Kingdom, IV–V Dynasty. The head of a young king wearing the crown of Upper Egypt. (The beard and one eye-ball are missing; one ear is chipped; the tip of the crown has been broken off and replaced). Diorite. The right eye-ball is made of fine marl, originally held in place by a copper band of which two small fragments (completely oxidized) remain. Height, 0.580.

Curatorial work during the past year has been devoted to the study of Chinese, Japanese, Korean, Tibetan, East Indian, Egyptian, Arabic, Persian, Aramaic, and Armenian objects of art, including manuscripts, and of the texts, inscriptions, or seals associated with them—and in the preparation of this material for Gallery records. Other things from some of these fields, and also Assyrian, Cretan, Byzantine, and European objects were sent or brought to the Director by their owners for expert opinion as to identity, provenance, age, quality, and so on. In all, 810 objects and 316 photographs of objects were submitted, and written or oral reports were made to the institutions or private owners who asked for this service. Written translations of 20 inscriptions in Oriental languages also were made upon request.

Changes in exhibition have involved a total of 75 objects, as follows:

Arabic and Persian calligraphy	20
Persian painting	18
Chinese bronze	14
Chinese gold	1
Chinese gold and iron	2
Chinese painting	5
Chinese porcelain	6
Chinese pottery	9

ATTENDANCE

The Gallery has been open to the public every day from 9 until 4:30 o'clock, with the exception of Mondays, Christmas Day, and New Year's Day.

The total attendance of visitors coming in at the main entrance was 120,241. One hundred eighty-six other visitors on Mondays makes the grand total 120,427. The total attendance for week-days, exclusive of Mondays, was 86,652; Sundays, 33,589. The average week-day attendance was 279; the average Sunday attendance, 646.

The highest monthly attendance was reached in July, 18,182; the lowest in December, 5,827.

There were 1,646 visitors to the main office during the year. The purposes of their visits were as follows:

For general information		466
To see objects in storage		503
Far Eastern paintings	109	
Tibetan paintings	1	
Near Eastern paintings and manuscripts	41	
East Indian paintings and manuscripts	3	
American paintings	50	
Whistler prints	15	
Oriental pottery, jade, bronzes, sculptures	195	
East Christian paintings	2	
Washington Manuscripts	87	
To read in the library		192
To make tracings and sketches from library books		6
To see building and installation		11
To obtain permission to photograph or sketch		10
To examine or purchase photographs		388
To submit objects for examination		168
To see members of the staff		173
To see the exhibition galleries on Mondays		53

LECTURES AND DOCENT SERVICE

Two illustrated lectures on Musulman Painting were given by Eustache de Lorey, Paris, Former Director of the French Institute of Arts and Archaeology, Damascus, Syria:

Friday, April 8: Wāsitī, a 13th century painter in Baghdad.
Saturday, April 9: Islam at grips with China.

One hundred and twenty-six persons attended these lectures.

Upon request, 9 groups, ranging from 6 to 17 persons (total 89), were given instruction in the study rooms. One group of 17 persons was given instruction in the storage rooms, and 10 groups ranging from 7 to 50 persons (total 213) were given docent service in the exhibition galleries.

PERSONNEL

On October 1, 1937, to the regret of all those associated with him, occurred the death of Frederick R. Brill, watchman, who had been at the Gallery since July 1, 1925.

William R. B. Acker, student assistant, returned from Japan on December 22, 1937.

On January 1, 1938, the title "Curator" was changed to "Director" and on May 11 the following titles of members of the staff became effective:

Grace Dunham Guest, assistant director.
Carl W. Bishop, associate in archeology.
Archibald G. Wenley, associate in research.

Grace T. Whitney worked intermittently at the Gallery between October 20, 1937, and June 30, 1938, on translations of Persian texts.

Respectfully submitted.

J. E. LODGE, *Director.*

Dr. C. G. ABBOT,
Secretary, Smithsonian Institution.

APPENDIX 5

REPORT ON THE BUREAU OF AMERICAN ETHNOLOGY

SIR: I have the honor to submit the following report on the field researches, office work, and other operations of the Bureau of American Ethnology during the fiscal year ended June 30, 1938, conducted in accordance with the act of Congress of June 28, 1937. The act referred to contains the following item:

American ethnology: For continuing ethnological researches among the American Indians and the natives of Hawaii, the excavation and preservation of archeologic remains under the direction of the Smithsonian Institution, including necessary employees, the preparation of manuscripts, drawings, and illustrations, the purchase of books and periodicals, and traveling expenses, $58,730.

SYSTEMATIC RESEARCHES

During the greater part of the fiscal year, M. W. Stirling, Chief of the Bureau, was in Washington engaged in administrative duties and in preparation of various publications.

From the latter part of January until the middle of March, 1938, Mr. Stirling was in Mexico examining archeological sites and museum collections. A site in the Canton of the Tuxtlas south of Veracruz was selected for excavation during the winter of 1938–39.

At the beginning of the fiscal year, Dr. John R. Swanton, ethnologist, was engaged in the preparation of the final report of his researches in the interests of the United States De Soto Expedition Commission, of which he is chairman. One field expedition was undertaken in connection with this research. It was directed in the first instance to the southern part of Clarke County, Alabama, at the invitation of James Y. Brame, Jr., of Montgomery, an indefatigable student of the route of De Soto, who hoped that he had discovered the site of the old town of Mabila, where occurred a notable battle between the Spaniards and Indians on October 18, 1540. The site in question, at a place called Lower James Hammock, on the bluff above Choctaw Lake, proved to be an interesting one and specimens of certain novelty types of pottery were obtained, but the question as to its identity with Mabila is still in doubt, the evidence being rather negative. After this work was finished an attempt was made to locate other Indian town sites in the southeastern part of the county, but, aside from a very small one previously identified by Mr.

Brame, nothing was found, there being, in fact, a singular dearth of Indian remains in this county in the section where it would be natural to look for Mabila. In the southwestern part of the county, however, there is a spot to which the Indians resorted for salt, one noted on early French maps, and here a considerable collection of potsherds was made and a number of pictures of the site taken. While Dr. Swanton was engaged in this investigation, the Choctaw Hunting and Fishing Club kindly extended the use of its camp at Choctaw Bluff.

After returning to Montgomery, Dr. Swanton proceeded to Tuscaloosa and David De Jarnette, assistant to Prof. Walter S. Jones, took him to Scottsboro and afterward on a number of trips along the part of the Tennessee River valley believed to have been traversed by De Soto. It seems to be indicated rather clearly that the Spaniards crossed and recrossed this several times. Before returning to Washington Dr. Swanton attended a meeting on October 29–30 called by the De Soto Committee of the Society of the Colonial Dames of America in preparation for a celebration of the quadricentennial of the passage of the Mississippi by De Soto, and he delivered an address at one of the sessions.

Dr. Swanton has also added some further material to his large paper on the Indians of the Southeast.

In December he presided as vice-president over several sessions of Section H, American Association for the Advancement of Science, at Indianapolis.

In March he was appointed to the United States Board on Geographical Names to occupy the place made vacant by the death of J. N. B. Hewitt, and he attended the twelfth annual meeting on May 23.

Dr. Truman Michelson, ethnologist, left Washington early in July 1937 to undertake field work among the Montagnais-Naskapi Indians of the northern shore of the St. Lawrence River and vicinity. This work was made possible through a generous grant-in-aid made by the American Council of Learned Societies. He arrived at Natashquan July 12 and spent 18 days there, following which he continued his investigations at Seven Islands, Moisie, and Bersimis. Owing to the migratory habits of the Indians Dr. Michelson was able to get data not only on Indians of the localities named but also others in this region, including Mingan, St. Margeret's River, Godbout, Shelterbay, and Sheldrake. He was also able to check up his previous information on the Indians of Davis Inlet, far north on the Labrador coast; and by good fortune came in contact with an Indian of a band from the northeast corner of Lake Kaniapiskau—a band barely known to the scientific world. The principal object was to complete

a map showing the distribution and interrelations of the Cree and Montagnais-Naskapi dialects. In addition to the linguistic work which was the primary purpose of the trip, many new ethnological data were obtained, together with certain observations in physical anthropology. The remainder of the year was spent in Washington in the preparation of manuscripts and in routine work.

At the beginning of the fiscal year Dr. John P. Harrington, ethnologist, finished a comparative study of the Tano-Kiowan family of languages, a compact body of dialects which have inherited the same phonetics, grammatical peculiarities, and vocabulary, although the Tanoan branch is typically Pueblo in culture while the Kiowa branch is equally typical of the Western Plains culture. No linguistic study shows better how habitat has produced two cultures by migration from a linguistic nucleus which had perhaps originally a third culture—possibly like that of the Flatheads of the northern Rockies, from which region the linguistic progenitors of both Tanoans and Kiowans apparently came. The Tano-Kiowan situation, however, is clearer than the surprisingly similar Athapascan situation, since there is historic information on the northern origin of the Kiowa, whereas the migration of any body of southern Athapascans from the north still remains theoretical. It is established that both the Tanoans and the southern Athapascans of the southwestern United States are of comparatively recent northern origin, at least as far as their language-transmitting ancestors are concerned.

Returning to the study of the Devils Tower, which has a bearing on the Tano-Kiowan provenience problem, Dr. Harrington was assisted materially by Newell F. Joyner, custodian of the Devils Tower National Monument, Devils Tower, Wyo., who supplied a mass of material, including maps and other data. If the Kiowans came from the somewhat far north, it is certain that their linguistic relatives, the Tanoans, did also.

Working by similar methods, Dr. Harrington also made a study of the Athapascan peoples. Here we have a northern linguistic nucleus still extant, not of the past but of the present, and a family of languages more intimately associated with the problem of the original entry of man from Siberia into America, since if we exclude the somewhat aloof-standing Eskimo, all the territory of America nearest Asia is occupied by the Athapascan and related Tlingit tongues.

Following up Goddard's discovery that the Kiowa-Apache-Lipan-Jicarilla form a separate language group, having shifted over-aspirated *tx* to *kh*, that is, the *x* having assimilated the *t* to its articulatory position, Thomas' recent work on the Prairie Apaches was found of interest. A considerable list of the Prairie Apaches are

known to us by name through the old Spanish historical documents of New Mexico, showing that the *kh* language was spoken by many tribes which covered a large area of the High Plains. The northernmost of these tribes is reported in old Spanish sources from what is now northeastern Colorado, only 150 miles south of the Black Hills. This takes away the element of novelty from the fact that the Kiowa-Apache joined the Kiowa in the Black Hills region about the year 1800 or earlier, and shows that the Kiowa-Apache also were merely one of the *kh* speaking tribes, typically Prairie Apaches, and not an Athapascan people en route migrating from Canada, as Goddard at first conjectured. A report was finished on the northern provenience of the Navaho and Apache.

Considerable time was also spent on a new sign language study, through Kiowa informants and other sources, bringing out additional information regarding the nature and structure of this interesting Plains Indian invention.

At the beginning of the fiscal year Dr. Frank H. H. Roberts, Jr., archeologist, was conducting excavations at the Lindenmeier Site north of Fort Collins, Colo. This was a continuation of the program of investigations started in the fall of 1934 and carried on during succeeding summers. The location is one where Folsom man, one of the earliest known New World inhabitants, camped and made the weapons and tools that were used in killing and dressing the big game that constituted his main source of sustenance. Work was resumed in 1937 at the point where the 1936 activities terminated and at the end of the summer an area of some 2,800 square feet had been uncovered and numerous traces of occupation noted and studied. Several places were found where bison and other large animals had been dismembered, cooking fires lighted, and a feast enjoyed. At other places there were indications that individuals had been seated there manufacturing stone projectile points, knives, and scrapers. Many charts were drawn recording the nature of the assemblages of bones and stone implements and showing their distribution. In addition, 133 diagrams illustrating the character of the overlying deposits were prepared as the excavations progressed. These, together with the extensive notes on the work, add valuable data to the body of information on the mode of life and customs of the people. A collection of 735 specimens was obtained and among them were several new forms of knives, scrapers, and points. These broaden the knowledge relative to the general complex and nature of the material culture.

At the close of the excavating season Dr. Roberts proceeded to North Platte, Nebr., where he inspected a number of collections belonging to local residents and visited the sites where many of them

were found. Through the interest of R. R. Langford, of North Platte, he was able to see a number of locations where Folsom-type objects have been found and add to the series of notes that is being kept on the subject of Folsom distribution. From North Platte Dr. Roberts returned to Washington.

The winter and spring months were devoted to office duties. These included the study of the material obtained during the summer's excavations and the revision and completion for publication of a manuscript on archeological work done in the Whitewater District in eastern Arizona. Besides completely revising the text of this report, 15 additional plans and diagrams were drawn to augment those already prepared. This manuscript was turned over to the editor and is to appear as Bulletin 121 of the Bureau of American Ethnology. With the permission of the Chief of the Bureau and the Secretary of the Smithsonian Institution, several short manuscripts were prepared for publication in anthropological journals and other professional papers.

Dr. Roberts left Washington on June 7, 1938, for Fort Collins, Colo., and again resumed excavations at the Lindenmeier Site. At the close of the fiscal year the diggings had been reopened and a number of specimens obtained. These included several pieces of bone that bear evidence of attempts at engraving designs on them and give some indications of a certain amount of artistic effort on the part of Folsom men.

Dr. J. H. Steward, ethnologist, remained in Washington during the greater part of the fiscal year and completed his final report on the tribes of the Great Basin-Plateau area. This was submitted to the editor and will appear as Bulletin 120 of the Bureau. In anticipation of an extended expedition to South America, Dr. Steward spent considerable time in making preparations for his projected ethnological studies in the western part of South America. On April 20 he left Washington for Ecuador in order to begin this work. The end of the fiscal year found him still in Ecuador working among the highland Indians.

EDITORIAL WORK AND PUBLICATIONS

The editing of the publications of the Bureau was continued through the year by Stanley Searles, editor.

BULLETINS ISSUED DURING THE YEAR

115. Journal of Rudolph Friederich Kurz, edited by J. N. B. Hewitt.
116. Ancient Caves of the Great Salt Lake Region, by Julian H. Steward.
117. Historical and Ethnographical Material on the Jivaro Indians, by M. W. Stirling.

RELEASED FOR PUBLICATION

118. An Archaeological Survey of the Norris Basin in Eastern Tennessee, by Maj. William S. Webb.

The index of Schoolcraft's Indian Tribes has been almost completed.

Work has been done on other manuscripts in the custody of the editor.

Publications distributed totaled 16,569.

LIBRARY

There has been no change in the library staff. Accessions during the fiscal year totaled 395.

Eight new exchanges were added during the year, three of these being large, important sets, one domestic and two foreign.

Library of Congress cards have been obtained for practically all of the new material received as well as for some older items. Analytical entries have been made for all periodical items in the Bureau's field received since April 1936. The depository set of Library of Congress catalog cards is now installed in working order and has proved to be a great help to the staff as well as to those in the library.

The librarian attended the meetings of the Inter-American Bibliographical and Historical Association in February 1938, and made arrangements to exchange cards for South and Central American Indian languages and folk-lore entries with Dr. Boggs, of the University of North Carolina.

ILLUSTRATIONS

Following is a summary of work accomplished by E. G. Cassedy, illustrator:

Line drawings	175
Maps	25
Photos retouched	28
Lettering jobs	96
Plates assembled	213
Drawings, etc., prepared for engraver	415
Diagrams and charts	7
Graphs	6
Mechanical drawings	4
Wash drawings	1
Total	970

Accession No.

COLLECTIONS

144,343. One earthenware water jar from the pueblo of Acoma, and one decorated basket made by the Aleuts of southwestern Alaska. (2 specimens.)

Accession No.

146,287. Three figurine pottery fragments and three figurine pottery heads from a railway cut near the Aguan River, Maloa District, northeast Honduras, Central America. Purchased from J. R. Allsopp. (6 specimens.)

146,639. Potsherds, arrowpoints, shell bead, and fragment of worked shell from Liberty and Dade Counties, Fla. Collected by M. W. Stirling. (6 specimens.)

148,063. Earthenware vessels and fragments from Ulua River, Comayagua River, and Lake Yojoa regions of Honduras, collected in 1936 by Smithsonian-Harvard University Expedition under Dr. W. D. Strong. (93 specimens.)

MISCELLANEOUS

During the course of the year information was furnished by members of the Bureau staff in reply to numerous inquiries concerning the North American Indians, both past and present, and the Mexican peoples of the prehistoric and early historic periods. Various specimens sent to the Bureau were identified and data on them furnished for their owners.

Personnel.—Dr. W. D. Strong, anthropologist, resigned August 31, 1937. J. N. B. Hewitt, ethnologist, died October 14, 1937.

Respectfully submitted.

M. W. Stirling, *Chief.*

Dr. C. G. Abbot,
Secretary, Smithsonian Institution.

APPENDIX 6

REPORT ON THE INTERNATIONAL EXCHANGE SERVICE

SIR: I beg to submit the following report on the activities of the International Exchange Service during the fiscal year ended June 30, 1938:

The amount granted by Congress for that year was $44,260, the same as appropriated for 1937. The collections from repayments were $3,577.12, making the total resources available $47,837.12.

The number of packages handled was 719,121, a gain of 61,775. The weight was 656,119 pounds, an increase of 4,658 pounds.

The number and weight of packages sent and received through the Exchange Service is given below:

	Packages		Weight	
	Sent	Received	Sent	Received
			Pounds	*Pounds*
United States parliamentary documents sent abroad	363, 823		135, 064	
Publications received in return for parliamentary documents		9, 607		26, 711
United States departmental documents sent abroad	123, 182		122, 300	
Publications received in return for departmental documents		10, 231		33, 537
Miscellaneous scientific and literary publications sent abroad	154, 730		225, 006	
Miscellaneous scientific and literary publications received from abroad for distribution in the United States		57, 548		113, 501
Total	641, 735	77, 386	482, 370	173, 749
Grand total	719, 121		656, 119	

There were shipped abroad 2,639 boxes, an increase of 19 over the preceding year. Of these boxes, 538 were for depositories of full sets of United States governmental documents, and the remainder (2,101) were for distribution to miscellaneous establishments and individuals. There were transmitted by mail 111,475 packages, an increase over last year of 24,179.

For a number of years the government franking privilege has been in existence between the United States and Canada, Cuba, Mexico, Newfoundland, and Panama, and exchange packages for these countries, therefore, have been sent direct to their destinations by mail and not through the exchange bureaus in the respective countries. In recent months this privilege has been extended. The complete list of the countries with which this privilege is now in effect is as

follows: Canada, Chile, Colombia, Costa Rica, Cuba, Dominican Republic, Ecuador, Guatemala, Haiti, Honduras, Mexico, Newfoundland (including Labrador), Nicaragua, Panama, Paraguay, Peru, Salvador, Uruguay, and Venezuela.

Shipments of exchanges to Spain, owing to the disturbed political conditions in that country, have been suspended since August 1936.

Owing to the war in China, consignments to that country were suspended in August 1937. The Chinese Bureau of International Exchange, having moved its office from Nanking to Chungking, requested the Institution to forward shipments to its new address, and at the close of the year a large consignment was being prepared for transmission to that bureau.

Packages for the National Library of Peiping, the Engineering Reference Library, Nanking, and the Library Association of China, instead of being included with the regular consignments to the new address of the Chinese Exchange Bureau, are being forwarded to Hong Kong in care of the Fung Ping Shan Chinese Library, at the request of Dr. T. L. Yuan, who is officially connected with those organizations.

FOREIGN DEPOSITORIES OF GOVERNMENTAL DOCUMENTS

There are forwarded to foreign depositories 111 sets of United States official publications, 61 being full sets and 50, partial sets. The depository of the full set sent to Chile has been changed from Biblioteca del Congreso to Biblioteca Nacional, Santiago; the depository in Mexico, from Biblioteca Nacional to Departamento Autónomo de Publicidad y Propaganda, Mexico; and the depository in the Soviet Republic, from State Central Book Chamber to All-Union Lenin Library, Moscow.

DEPOSITORIES OF FULL SETS

Argentina: Ministerio de Relaciones Exteriores, Buenos Aires.
  Buenos Aires: Biblioteca de la Universidad Nacional de La Plata, La Plata. (Depository of the Province of Buenos Aires.)
Australia: Commonwealth Parliament and National Library, Canberra.
  New South Wales: Public Library of New South Wales, Sydney.
  Queensland: Parliamentary Library, Brisbane.
  South Australia: Parliamentary Library, Adelaide.
  Tasmania: Parliamentary Library, Hobart.
  Victoria: Public Library of Victoria, Melbourne.
  Western Australia: Public Library of Western Australia, Perth.
Belgium: Bibliothèque Royale, Bruxelles.
Brazil: Bibliotheca Nacional, Rio de Janeiro.
Canada: Library of Parliament, Ottawa.
  Manitoba: Provincial Library, Winnipeg.
  Ontario: Legislative Library, Toronto.
  Quebec: Library of the Legislature of the Province of Quebec.
Chile: Biblioteca Nacional, Santiago.

CHINA: Bureau of International Exchange, Ministry of Education, Chungking.
COLOMBIA: Biblioteca Nacional, Bogotá.
COSTA RICA: Oficina de Depósito y Canje Internacional de Publicaciones, San José.
CUBA: Secretaría de Estado, Dirección de Relaciones Culturales, Habana.
CZECHOSLOVAKIA: Bibliothèque de l'Assemblée Nationale, Prague.
DENMARK: Kongelige Bibliotheket, Copenhagen.
EGYPT: Bureau des Publications, Ministère des Finances, Cairo.
ESTONIA: Riigiraamatukogu (State Library), Tallinn.
FRANCE: Bibliothèque Nationale, Paris.
GEGMANY: Reichstauschstelle im Reichsministerium für Wissenschaft, Ergiehung und Volksbildung, Berlin, N. W. 7.
AUSTRIA: National Bibliothek, Wien, I.
BADEN: Universitäts-Bibliothek, Freiburg. (Depository of the State of Baden.)
BAVARIA: Bayerische Staatsbibliothek, München.
PRUSSIA: Preussische Staatsbibliothek, Berlin, N. W. 7.
SAXONY: Sächsische Landesbibliothek, Dresden—N. 6.
WURTEMBURG: Landesbibliothek, Stuttgart.
GREAT BRITAIN:
ENGLAND: British Museum, London.
GLASGOW: City Librarian, Mitchell Library, Glasgow.
LONDON: London School of Economics and Political Science. (Depository of the London County Council.)
HUNGARY: A Magyar országgyülés könyvtará, Budapest.
INDIA: Imperial Library, Calcutta.
IRELAND: National Library of Ireland, Dublin.
ITALY: Ministero dell'Educazione Nazionale, Rome.
JAPAN: Imperial Library of Japan, Tokyo.
LATVIA: Bibliothèque d'État, Riga.
LEAGUE OF NATIONS: Library of the League of Nations, Geneva, Switzerland.
MEXICO: Departamento Autónomo de Prensa y Publicidad, Mexico, D. F.
NETHERLANDS: Royal Library, The Hague.
NEW ZEALAND: General Assembly Library, Wellington.
NORTHERN IRELAND: H. M. Stationery Office, Belfast.
NORWAY: Universitets-Bibliothek, Oslo. (Depository of the Government of Norway.)
PERU: Sección de Propaganda y Publicaciones, Ministerio de Relaciones Exteriores, Lima.
POLAND: Bibliothèque Nationale, Warsaw.
PORTUGAL: Bibliotheca Nacional, Lisbon.
RUMANIA: Academia Română, Bucharest.
SPAIN: Servicio de Cambio Internacional de Publicaciones, Paseo de Recoletos 20, Madrid. Shipments suspended since August 1936.
SWEDEN: Kungliga Biblioteket, Stockholm.
SWITZERLAND: Bibliothèque Centrale Fédérale, Berne.
TURKEY: Ministère de l'Instruction Publique, Ankara.
UNION OF SOUTH AFRICA: State Library, Pretoria, Transvaal.
UNION OF SOVIET SOCIALIST REPUBLICS: All-Union Lenin Library, Moscow 115.
UKRAINE: All-Ukrainian Association for Cultural Relations with Foreign Countries, Kiev.
URUGUAY: Oficina de Canje Internacional de Publicaciones, Montevideo.
VENEZUELA: Biblioteca Nacional, Caracas.
YUGOSLAVIA: Ministère de l'Éducation, Belgrade.

DEPOSITORIES OF PARTIAL SETS

AFGHANISTAN: Ministry of Foreign Affairs, Publications Department, Kabul.
BOLIVIA: Biblioteca del H. Congreso Nacional, La Paz.
BRAZIL:
  MINAS GERAES: Directoria Geral de Estatistica em Minas, Bello Horizonte.
  RIO DE JANEIRO: Bibliotheca da Assemblea Legislativa do Estado, Nictheroy.
BRITISH GUIANA: Government Secretary's Office, Georgetown, Demerara.
BULGARIA: Ministère des Affaires Étrangères, Sofia.
CANADA:
  ALBERTA: Provincial Library, Edmonton.
  BRITISH COLUMBIA: Provincial Library, Victoria.
  NEW BRUNSWICK: Legislative Library, Fredericton.
  NOVA SCOTIA: Provincial Secretary of Nova Scotia, Halifax.
  PRINCE EDWARD ISLAND: Legislative Library, Charlottetown.
  SASKATCHEWAN: Legislative Library, Regina.
CEYLON: Chief Secretary's Office (Record Department of the Library), Colombo.
CHINA: National Library of Peiping, % Fung Ping Shan Chinese Library, Hong Kong.
DANZIG: Stadtbibliothek, Danzig.
DOMINICAN REPUBLIC: Biblioteca del Senado, Ciudad Trujillo.
ECUADOR: Biblioteca Nacional, Quito.
FINLAND: Parliamentary Library, Helsingfors.
GERMANY:
  BREMEN: Staatsbibliothek.
  HAMBURG: Staats-und Universitäts-Bibliothek.
  HESSE: Universitäts-Bibliothek, Giessen.
  LÜBECK: President of the Senate.
  THURINGIA: Rothenberg-Bibliothek, Landesuniversität, Jena.
  VIENNA: Magistrat der Stadt Wien, Abteilung 51-Statistik.
GREECE: Library of Parliament, Athens.
GUATEMALA: Biblioteca Nacional, Guatemala.
HAITI: Secrétaire d'Etat des Relations Extérieures, Port-au-Prince.
HONDURAS: Biblioteca y Archivo Nacionales, Tegucigalpa.
ICELAND: National Library, Reykjavik.
INDIA:
  ASSAM: General and Judicial Department, Shillong.
  BENGAL: Secretary, Bengal Legislative Council Department, Council House, Calcutta.
  BIHAR and ORISSA: Revenue Department, Patna.
  BOMBAY: Undersecretary to the Government of Bombay, General Department, Bombay.
  BURMA: Secretary to the Government of Burma, Education Department, Rangoon.
  CENTRAL PROVINCES: General Administration Department, Nagpur.
  MADRAS: Chief Secretary to the Government of Madras, Public Department, Madras.
  PUNJAB: Chief Secretary to the Government of the Punjab, Lahore.
  UNITED PROVINCES OF AGRA AND OUDH: University of Allahabad, Allahabad.
JAMAICA: Colonial Secretary, Kingston.
LIBERIA: Department of State, Monrovia.
LITHUANIA: Ministère des Affaires Étrangères, Kaunas (Kovno).
MALTA: Minister for the Treasury, Valletta.

NEWFOUNDLAND: Department of Home Affairs, St. John's.
NICARAGUA: Superintendente de Archivos Nacionales, Managua.
PANAMA: Secretaría de Relaciones Exteriores, Panama.
PARAGUAY: Secretario de la Presidencia de la República, Asunción.
SALVADOR: Ministerio de Relaciones Exteriores, San Salvador.
SIAM: Department of Foreign Affairs, Bangkok.
STRAITS SETTLEMENTS: Colonial Secretary, Singapore.
VATICAN CITY: Biblioteca Apostolica Vaticana, Vatican City, Italy.

INTERPARLIAMENTARY EXCHANGE OF THE OFFICIAL JOURNAL

The total number of copies of the Congressional Record and Federal Register sent to foreign depositories has been reduced to 104, the copies sent to the Governor of Latakia having been discontinued. Several changes have been made in the establishments to which those documents are sent. A list of the depositories now receiving those documents is given below:

DEPOSITORIES OF CONGRESSIONAL RECORD

ALBANIA: Ministrija Mbretnore e Punëvetë Jashtme, Tirana.
ARGENTINA:
Biblioteca del Congreso Nacional, Buenos Aires.
Cámara de Diputados, Oficina de Información Parlamentaria, Buenos Aires.
Boletin Oficial de la República Argentina, Ministerio de Justicia e Instrucción Pública, Buenos Aires.
AUSTRALIA:
Library of the Commonwealth Parliament, Canberra.
NEW SOUTH WALES: Library of Parliament of New South Wales, Sydney.
QUEENSLAND: Chief Secretary's Office, Brisbane.
WESTERN AUSTRALIA: Library of Parliament of Western Australia, Perth.
BELGIUM: Bibliothèque de la Chambre des Représentants, Bruxelles.
BOLIVIA: Biblioteca del H. Congreso Nacional, La Paz.
BRAZIL:
Bibliotheca do Congresso Nacional, Rio de Janeiro.
AMAZONAS: Archivo, Bibliotheca e Imprensa Publica, Manáos.
BAHIA: Governador do Estado da Bahia, São Salvador.
ESPIRITO SANTO: Presidencia do Estado do Espirito Santo, Victoria.
RIO GRANDE DO SUL: "A Federação," Porto Alegre.
SERGIPE: Bibliotheca Publica do Estado de Sergipe, Aracajú.
SÃO PAULO: Diario Official do Estado de São Paulo, São Paulo.
BRITISH HONDURAS: Colonial Secretary, Belize.
CANADA:
Library of Parliament, Ottawa.
Clerk of the Senate, Houses of Parliament, Ottawa.
CHINA: National Central Library, Nanking.
CUBA: Biblioteca del Capitolio, Habana.
CZECHOSLOVAKIA: Bibliothèque de l'Assemblée Nationale, Prague.
DENMARK: Rigsdagens Bureau, Copenhagen.
EGYPT:
Chambre des Députés, Cairo.
Sénat, Cairo.

FRANCE:

Chambre des Députés, Service de l'Information Parlementaire Étrangère, Paris.

Bibliothèque du Sénat, au Palais du Luxembourg, Paris.

Bureau de Documentation Générale, Ministère des Finances, Paris I.

Bibliothèque, Direction des Accords commerciaux, Ministère du Commerce, Paris.

GERMANY:

Deutsche Reichstags-Bibliothek, Berlin, N. W. 7.

Reichsfinanzministerium, Berlin, W. 8.

ANHALT: Anhaltische Landesbücherei, Dessau.

AUSTRIA: Bibliothek im Parlaments, Wien, I.

BRAUNSCHWEIG: Bibliothek des Braunschweigischen Staatsministeriums, Braunschweig.

MECKLENBURG: Staatsministerium, Schwerin.

OLDENBURG: Oldenburgisches Staatsministerium, Oldenburg i. O.

SCHAUMBURG-LIPPE: Schaumburg-Lippische Landesregierung, Bückeburg.

GIBRALTAR: Gibraltar Garrison Library Committee, Gibraltar.

GREAT BRITAIN: Library of the Foreign Office, London.

GREECE: Library of Parliament, Athens.

GUATEMALA: Biblioteca de la Asamblea Legislativa, Guatemala.

HONDURAS: Biblioteca del Congreso Nacional, Tegucigalpa.

HUNGARY: A Magyar országgyülés könyvtará, Budapest.

INDIA: Legislative Department, Simla.

INDOCHINA: Gouveneur Général de l'Indochine, Hanoi.

IRAN: Library of the Iranian Parliament, Téhéran.

IRAQ: Chamber of Deputies, Baghdad.

IRISH FREE STATE: Dail Eireann, Dublin.

ITALY:

Biblioteca della Camera dei Deputati, Rome.

Biblioteca del Senato del Regno, Rome.

Ufficio degli Studi Legislativi, Senato del Regno, Rome.

LATVIA: Valsts Biblioteka, Riga.

LEAGUE OF NATIONS: Library of the League of Nations, Geneva, Switzerland.

LEBANON: Ministère des Finances de la Republique Libanaise, Service du Matériel, Beirut.

LIBERIA: Department of State, Monrovia.

MEXICO: Departamento Autónomo de Prensa y Publicidad, Mexico, D. F.

AGUASCALIENTES: Gobernador del Estado de Aguascalientes, Aguascalientes.

CAMPECHE: Gobernador del Estado de Campeche, Campeche.

CHIAPAS: Gobernador del Estado de Chiapas, Tuxtla Gutierrez.

CHIHUAHUA: Gobernador del Estado de Chihuahua, Chihuahua.

COAHUILA: Periódico Oficial del Estado de Coahuila, Palacio de Gobierno, Saltillo.

COLIMA: Gobernador del Estado de Colima, Colima.

DURANGO: Gobernador Constitucional del Estado de Durango, Durango.

GUANAJUATO: Secretaría General de Gobierno del Estado, Guanajuato.

GUERRERO: Gobernador del Estado de Guerrero, Chilpancingo.

JALISCO: Biblioteca del Estado, Guadalajara.

LOWER CALIFORNIA: Gobernador del Distrito Norte, Mexicali, B. C., Mexico.

MEXICO: Gaceta del Gobierno, Toluca, Mexico.
MICHOACÁN: Secretaría General de Gobierno del Estado de Michoacán, Morelia.
MORELOS: Palacio de Gobierno, Cuernavaca.
NAYARIT: Gobernador de Nayarit, Tepic.
NUEVO LEON: Biblioteca del Estado, Monterey.
OAXACA: Periódico Oficial, Palacio de Gobierno, Oaxaca.
PUEBLA: Secretaría General de Gobierno, Puebla.
QUERETARO: Secretaria general de Gobierno, Sección de Archivo, Queretaro.
SAN LUIS POTOSI: Congreso del Estado, San Luis Potosi.
SINALOA: Gobernador del Estado de Sinaloa, Culiacan.
SONORA: Gobernador del Estado de Sonora, Hermosillo.
TABASCO: Secretaría General de Gobierno, Sección 3a, Ramo de Prensa, Villahermosa.
TAMAULIPAS: Secretaría General de Gobierno, Victoria.
TLAXCALA: Secretaría de Gobierno del Estado, Tlaxcala.
VERACRUZ: Gobernador del Estado de Veracruz, Departamento de Gobernación y Justicia, Jalapa.
YUCATÁN: Gobernador del Estado de Yucatán, Mérida, Yucatán.

NETHERLANDS INDIES: Volksraad von Nederlandsch-Indië, Batavia, Java.
NEW ZEALAND: General Assembly Library, Wellington.
NORWAY: Storthingets Bibliothek, Oslo.
PERU: Cámara de Diputados, Lima.
POLAND: Bibljoteka Narodowa, Warsaw.
PORTUGAL: Secretario da Assemblea Nacional, Lisboa.
RUMANIA:
Bibliothèque de la Chambre des Députés, Bucharest.
Ministère des Affaires Étrangères, Bucharest.
SPAIN:
Biblioteca del Congreso Nacional, Madrid.
Catalunya: Biblioteca del Parlament de Catalunya, Barcelona.
SWITZERLAND: Bibliothèque de l'Assemblée Fédérale Suisse, Berne.
Bern: Staatskanzlei des Kantons Bern.
St. Gallen: Staatskanzlei des Kantons St. Gallen.
Schaffhausen: Staatskanzlei des Kantons Schaffhausen.
Zürich: Staatskanzlei des Kantons Zürich.
TURKEY: Turkish Grand National Assembly, Ankara.
UNION OF SOUTH AFRICA:
Library of Parliament, Cape Town, Cape of Good Hope.
State Library, Pretoria, Transvaal.
URUGUAY: Diario Oficial, Calle Florida 1178, Montevideo.
VENEZUELA: Biblioteca del Congreso, Caracas.
VATICAN CITY: Biblioteca Apostolica Vaticana, Vatican City, Italy.

FOREIGN EXCHANGE AGENCIES

ALGERIA, via France.
ANGOLA, via Portugal.
ARGENTINA: Comisión Protectora de Bibliotecas Populares, Canje Internacional. Calle Callao 1540, Buenos Aires.
AUSTRIA: Internationale Austauschstelle, National-Bibliothek, Wien, I.
AZORES, via Portugal.
BELGIUM: Service Belge des Échanges Internationaux, Bibliothèque Royale de Belgique, Bruxelles.

BOLIVIA: Oficina Nacional de Estadística, La Paz.
BRAZIL: Serviço de Permutações Internacionaes, Bibliotheca Nacional, Rio de Janeiro.
BRITISH GUIANA: Royal Agricultural and Commercial Society, Georgetown.
BRITISH HONDURAS: Colonial Secretary, Belize.
BULGARIA: Sent by mail.
CANADA: Sent by mail.
CANARY ISLANDS, via Spain.
CHILE: Sent by mail.
CHINA: Bureau of International Exchange, Ministry of Education, Chungking.
COLOMBIA: Sent by mail.
COSTA RICA: Sent by mail.
CUBA: Sent by mail.
CZECHOSLOVAKIA: Service Tchécoslovaque des Échanges Internationaux, Bibliothèque de l'Assemblèe Nationale, Prague 1–79.
DANZIG: Amt für den Internationalen Schriftenaustausch der Freien Stadt Danzig, Stadtbibliothek, Danzig.
DENMARK: Service Danois des Échanges Internationaux, Kongelige Danske Videnskabernes Selskab, Copenhagen V.
DOMINICAN REPUBLIC: Sent by mail.
ECUADOR: Sent by mail.
EGYPT: Government Press, Publications Office, Bulaq, Cairo.
ESTONIA: Riigiraamatukogu (State Library), Tallinn.
FINLAND: Delegation of the Scientific Societies of Finland, Kasärngatan 24, Helsingfors.
FRANCE: Service Français des Échanges Internationaux, 110 Rue de Grenelle, Paris.
GERMANY: Amerika-Institut, Universitätstrasse 8, Berlin, N. W. 7.
GREAT BRITAIN AND IRELAND: Wheldon & Wesley, 2–4 Earnshaw St., New Oxford St., London, W. C. 2.
GREECE: Bibliothèque Nationale, Athens.
GREENLAND, via Denmark.
GUATEMALA: Sent by mail.
HAITI: Sent by mail.
HONDURAS: Sent by mail.
HUNGARY: Hungarian Libraries Board, Ferenciektere 5, Budapest, IV.
ICELAND, via Denmark.
INDIA: Superintendent of Government Printing and Stationery, Bombay.
ITALY: Ufficio degli Scambi Internazionali, Ministero dell' Educazione Nazionale, Rome.
JAMAICA: Institute of Jamaica, Kingston.
JAPAN: Imperial Library of Japan, Uyeno Park, Tokyo.
JAVA, via Netherlands.
LATVIA: Service des Échanges Internationaux, Bibliothèque d'Etat de Lettonie, Riga.
LIBERIA: Bureau of Exchanges, Department of State, Monrovia.
LITHUANIA: Sent by mail.
LOURENÇO MARQUEZ, via Portugal.
LUXEMBOURG, via Belgium.
MADAGASCAR, via France.
MADEIRA, via Portugal.
MEXICO: Sent by mail.
MOZAMBIQUE, via Portugal.

NETHERLANDS: International Exchange Bureau of the Netherlands, Royal Library, The Hague.
NEWFOUNDLAND and LABRADOR: Sent by mail.
NEW SOUTH WALES: Public Library of New South Wales, Sydney.
NEW ZEALAND: General Assembly Library, Wellington.
NICARAGUA: Sent by mail.
NORWAY: Service Norvégien des Échanges Internationaux, Bibliothèque de l'Université Royale, Oslo.
PALESTINE: Jewish National and University Library, Jerusalem.
PANAMA: Sent by mail.
PARAGUAY: Sent by mail.
PERU: Sent by mail.
POLAND: Service Polonais des Échanges Internationaux, Bibliothèque Nationale, Warsaw.
PORTUGAL: Secção de Trocas Internacionaes, Bibliotheca Nacional, Lisboa.
QUEENSLAND: Bureau of Exchanges of International Publications, Chief Secretary's Office, Brisbane.
RUMANIA: Bureau des Échanges Internationaux, Institut Météorologique Central, Bucharest.
SALVADOR: Sent by mail.
SIAM: Department of Foreign Affairs, Bangkok.
SOUTH AUSTRALIA: South Australian Government Exchanges Bureau, Government Printing and Stationery Office, Adelaide.
SPAIN: Servicio de Cambio Internacional de Publicaciones, Paseo de Recoletos 20, bajo derecha, Madrid. Shipments suspended since August 1936.
SUMATRA: via Netherlands.
SURINAM: Surinaamsche Koloniale Bibliotheek, Paramaribo.
SWEDEN: Kongliga Svenska Vetenskaps Akademien, Stockholm.
SWITZERLAND: Service Suisse des Échanges Internationaux, Bibliothèque Centrale Fédérale, Berne.
SYRIA: Sent by mail.
TASMANIA: Secretary to the Premier, Hobart.
TRINIDAD: Royal Victoria Institute of Trinidad and Tobago, Port-of-Spain.
TUNIS: via France.
TURKEY: Robert College, Istanbul.
UNION OF SOUTH AFRICA: Government Printing and Stationery Office, Cape Town, Cape of Good Hope.
UNION OF SOVIET SOCIALIST REPUBLICS: Library of the Academy of Sciences of the U. S. S. R., Exchange Service, Leningrad, V. O.
URUGUAY: Canje Internacional de Publicaciones, Ministerio de Relaciones Exteriores, Montevideo.
VENEZUELA: Sent by mail.
VICTORIA: Public Library of Victoria, Melbourne.
WESTERN AUSTRALIA: Public Library of Western Australia, Perth.
YUGOSLAVIA: Section des Échanges Internationaux, Ministère des Affaires Étrangères, Belgrade.

Respectfully submitted.

C. W. SHOEMAKER, *Chief Clerk.*

Dr. C. G. ABBOT,
Secretary, Smithsonian Institution.

APPENDIX 7

REPORT ON THE NATIONAL ZOOLOGICAL PARK

SIR: I have the honor to submit the following report on the operations of the National Zoological Park for the fiscal year ended June 30, 1938.

The regular appropriation made by Congress for the maintenance of the Park was $225,000, all of which was expended.

IMPROVEMENTS

The stone large-mammal house, which had been completed in the previous fiscal year, was stocked with animals during August and September 1937, and was opened to the public October 13, 1937, at the same time the giraffes, tapirs, African buffaloes, and gaurs that had been obtained on the National Geographic-Smithsonian Expedition were moved into it. This building was described and pictured in the last annual report.

W. P. A. work ceased on January 27, 1937, and was not resumed until September 1937. From this date until the close of the fiscal year W. P. A. workers were engaged mainly in cutting down the hill between the new large-mammal house and the refreshment stand, and in the construction of a stone retaining wall around the base of the hill. This work had not been completed at the close of the fiscal year. In addition, they demolished the octagonal elephant house—the first building ever constructed in the Zoo—which had been vacated when the elephants were moved to the new large-mammal house, and they also demolished the brick elephant house in accordance with the plans developed when the small-mammal house was placed immediately adjacent to it. The area occupied by these two buildings and the vicinity thereof was partially graded preparatory to the placing thereon of other small exhibits and the providing of pleasing open spaces. A small amount of work was accomplished in connection with other minor grounds improvement, tree surgery, and miscellaneous improvements.

Moving into the new quarters in the large-mammal house meant several days of big jobs. A contract was entered into with a concern equipped for moving large, heavy objects, and from September 1 to September 22, as the African and Sumatran elephants, the hippo-

114728—39——6

potamuses, and rhinoceros could be induced to enter large substantial crates, they were moved from their old quarters into the new, large-mammal house. Almost a full day was required for each animal moved, and in some cases the gates of the Park were closed so that visitors would not be in the way and would not be jeopardized should an accident occur. Every possible precaution had been taken to insure the successful accomplishment of the moves, and there was no unhappy incident. The suggestion had been frequently made that the elephants might be walked up to the building, but they had not been accustomed to discipline outside of their yards, and it was deemed inadvisable to do this. The crate used to move the elephants was 10 feet 10 inches high, 7 feet 4 inches wide, and 18 feet long, overall, and weighed 5½ tons. Other smaller animals, such as the tapirs and pigmy hippopotamuses, were moved by the Park force.

THE NATIONAL GEOGRAPHIC SOCIETY—SMITHSONIAN INSTITUTION EXPEDITION TO THE EAST INDIES

As was recorded in the previous annual report, this expedition left Washington in two sections. On January 19, 1937, Dr. Mann, director of the Park, Mrs. Mann, and Dr. Maynard Owen Williams, chief of the foreign editorial staff of the National Geographic Magazine, sailed from Vancouver, B. C., for the Orient. Making various stops en route, and visiting zoos in Japan, China, and Malaya, they finally reached Pematang Siantar, in Sumatra, where the base camp was established. On February 9, Roy Jennier, assistant head keeper, and Malcolm Davis, keeper of the National Zoological Park, left Washington with 28 American animals and, sailing by way of Cape of Good Hope, arrived at the Sumatra base camp on March 22.

While the headquarters had been near the north end of the Island of Sumatra, the animals were assembled from widely scattered points in the southern Asiatic and Malayan region. Dr. and Mrs. Mann had made trips to Siam, Johore, Singapore, Java, Celebes, and the Moluccas, and had arranged with numerous parties to assist in the collection of specimens. Noteworthy help was obtained from J. A. Coenraad, director of the zoo at Siantar; J. M. Lynkamp, manager of the Naga Hoeta Tea Estate, in Sumatra; and A. Baron Van Styrum, of the Deli Railroad. The giraffes and African buffaloes were loaded at Port Sudan, in accordance with arrangements that had been made with the game warden of the Khartoum Government, Egyptian Sudan.

His Highness, the Crown Prince of Johore, presented the expedition with a pair of black leopards and a fine Bennett's cassowary. From the Zoo at Fort de Kock, through C. Grootes, and from the Zoo at Batavia, through J. M. N. A. Niemans, were received a number of

valuable specimens. W. L. Basapa, of Singapore, presented a Baska turtle, and Dr. Harold Coolidge of the Harvard Primate Expedition, a pair of Himalayan bears.

This expedition was financed by the National Geographic Society, and the results to the Zoo were highly gratifying. On its return all members of the party except Dr. Williams arrived in New York September 27, 1937, where the shipment of 193 crates of animals was divided. Seventeen hoofed animals were placed in quarantine in the Bureau of Animal Industry's station at Athenia, N. J., and the remaining animals were brought to Washington by express. They were sorted at the express car and loaded into trucks destined to the respective buildings in the Zoo, and by noon of September 28 a large proportion of them were in their new quarters, taking baths, grooming themselves, and otherwise getting ready to receive visitors who were already arriving.

After the animals were finally counted and identified, it was found that the expedition had brought in the following:

Summary of animals brought back by the National Geographic Society—Smithsonian Institution East Indies Expedition, 1937

Class	Species	Individuals
Mammals	46	121
Birds	93	649
Reptiles and amphibians	30	109
Total	169	879

The collection included numerous species never before exhibited in the Zoo, and other species that had been badly needed. Among them were Asiatic tapirs, both species of orang-utans, a pair of gaur, 16 birds of paradise of 4 different species, and a great many other desirable birds. In the reptile collection were four species of cobras, including two fine specimens of Hamadryads.

NEEDS OF THE ZOO

In the previous annual report under this topic, the following appeared:

> The old frame shelter now housing the restaurant and concession stand is badly deteriorated and entirely inadequate to accommodate the large volume of business that has developed with the increasing attendance at the Zoo.

Construction of a suitable building would be a self-liquidating undertaking, as the annual revenue derived from the restaurant concession has been $6,012 per annum for the three years prior to July 1937, and for the following three years will be $9,012 per annum. This money is deposited in the United States Treasury to the credit of the General Fund, District of Columbia, and not available to the Zoo.

VISITORS FOR THE YEAR

There were substantial increases in the attendance for the year, both in individuals and in groups.

July	313, 700	February	165, 100
August	227, 000	March	290, 000
September	280, 400	April	313, 100
October	408, 300	May	359, 700
November	289, 500	June	225, 500
December	123, 050		
January	132, 300	Total	3,127, 650

The attendance of organizations, mainly classes of students, of which there is definite record, was 70,371 from 1,374 different schools in 23 States and the District of Columbia, as follows:

State	Number of persons	Number of parties	State	Number of persons	Number of parties
Alabama	20	1	New Hampshire	72	1
Connecticut	379	10	New Jersey	5, 768	66
Delaware	772	15	New York	3, 252	38
District of Columbia	14, 554	306	North Carolina	2, 507	73
Florida	107	1	Ohio	1, 813	51
Georgia	991	25	Pennsylvania	15, 408	308
Indiana	30	1	Rhode Island	75	2
Kentucky	25	1	South Carolina	609	18
Maine	134	3	Tennessee	202	6
Maryland	11, 866	195	Virginia	9, 695	209
Massachusetts	382	8	West Virginia	1, 052	22
Michigan	402	8			
Missouri	256	6	Total	70, 371	1, 374

About 3 o'clock every afternoon, except Sundays and holidays, a census is made of the cars parked on the Zoo grounds. During the year, 31,159 were so listed, representing every State in the Union, Canada, Mexico, Canal Zone, Alaska, Cuba, Panama, Hawaii, and Puerto Rico. Since the total number is merely a record of those actually parked at one time, it is not of value as indicating a total attendance but is of importance as showing the percentage attendance by States, Territories, and countries. The District of Columbia comprised slightly over 51 percent; Maryland, 19 percent; Virginia, 11 percent; and the remaining cars were from other States, Territories, and countries. During years in which counts have been made on Sunday as well as during the week it has been found that the percentage of cars from the District of Columbia, Maryland, and Virginia is less, and the percentage of the more distant States is correspondingly increased. This is brought about by tourists coming to the Zoo on Sundays when other points of interest are closed to them.

ACCESSIONS

Gifts.—A number of specimens were received as gifts during the year. Among the most interesting additions were two East African

hedgehogs from President Franklin D. Roosevelt; a Chapman's zebra from Mrs. Robert C. Winmill, Warrenton, Va.; a pair of dingos, one South African spitting cobra, one golden cobra, and one puff adder from the New York Zoological Park. From the Firestone Rubber Plantations, Liberia, through George Siebold, manager, were received a chimpanzee and a young leopard. The Florida Boy Scout contingent attending the jamboree in the city presented a collection of 33 reptiles from their State.

The field representatives of the United States Biological Survey continued their generosity in the form of various gifts, most important of which were two bison (one an albino) from the National Bison Range, Moiese, Mont.; three California murres, and one tufted puffin, through O. J. Murie, Seattle, Wash.

DONORS AND THEIR GIFTS

Miss Nelda Acker, Washington, D. C., 2 Pekin ducks.

Paul Akers, East Radford, Va., hog-nosed snake, fence lizard, 2 salamanders.

S. S. Alderman, Washington, D. C., Pekin duck.

H. A. Allard, Arlington, Va., raccoon.

Mrs. Archambault, Washington, D. C., great horned owl.

L. M. Ashley, Takoma Park, Md., American egret.

Atherton's Bird Store, Washington, D. C., Patas monkey.

Miss Selden Babcock, Washington, D. C., weasel.

Miss Amy Bailey, Washington, D. C., sparrow hawk.

B. D. Bailey, Wilson, N. C., barn owl.

S. M. Baker, Tomsbrook, Va., common crow.

A. T. Baldwin, Benning, D. C., double yellow-head parrot.

Baltimore Humane Society, Baltimore, Md., white-throated capuchin, sulphur-crested cockatoo.

Dr. Thomas Barbour, Cambridge, Mass., rhinoceros iguana, soft-shelled turtle, chicken tortoise.

G. Barksdale, Washington, D. C., silver pheasant.

Dr. R. S. Bassler, Washington, D. C., horned lizard.

J. H. Batt, Washington, D. C., opossum.

T. M. Battle, Washington, D. C., brown capuchin.

Bakai Baysoy, Washington, D. C., grass paroquet.

Miss Helen Beal, Washington, D. C., 2 ducks.

Philip M. Blossom, Ann Arbor, Mich., 6 gnome or kangaroo mice, desert kangaroo rat, bushy tailed woodrat.

C. F. Borden, Washington, D. C., 4 pigeons.

Boulder Dam Recreational Area, Boulder City, Nev., 2 chuckwallas, collared lizard.

Boy Scout Contingent, Florida, 2 Florida box turtles, gopher tortoise, pigmy rattlesnake, diamond-back rattlesnake, 2 water moccasins, 2 water snakes. chicken snake, corn snake, 2 garter snakes, 2 coachwhip snakes, horn snake, indigo snake, black snake, Florida king snake.

Mrs. M. Bradburn, Washington, D. C., vervet guenon.

Bradford Armstrong Farm, Wheaton, Md., 6 mallards.

Brookgreen Gardens, through P. L. Hovey, Georgetown, S. C., 6 southern fox squirrels.
Edward Brooks, Washington, D. C., opossum.
F. Charles Brown, Washington, D. C., barred owl.
Mrs. J. W. Brown, Washington, D. C., alligator.
B. J. Buck, Washington, D. C., black mallard.
G. R. Campbell, Lake Worth, Fla., coral snake, 2 rough-scaled green snakes, hog-nosed snake, yellow-lipped snake.
Wm. H. Carrico, Washington, D. C., mud puppy, common newt.
Martin Carter, York Harbor, Me., coatimundi.
H. L. Cassiday, Richmond, Va., red-shouldered hawk.
Miss Edith Chinn, Chevy Chase, Md., black widow spider.
Miss Nellie L. Condon, New York City, hog-nosed snake.
Miss Isabelle Cooke, Washington, D. C., tarantula.
R. T. Cox, Washington, D. C., Javan macaque.
G. L. Crawford, Mayaguez, Puerto Rico, rock iguana.
Ralph Crone, Washington, D. C., barn owl.
L. B. Cross, Washington, D. C., raccoon.
Culver Summer School, through Capt. S. R. Esten and Adm. Hugh Rodman, Culver, Ind., snapping turtle, box turtle, 7 geographic turtles, 16 painted turtles, 3 musk turtles, Cumberland turtle, spotted turtle, 4 chicken turtles, soft-shelled turtle, Blanding's turtle.
John M. Davis, Arlington, Va., 2 black raccoons.
Charles F. Denley, Glenmont, Md., Siamese crested fire-back pheasant, cheer pheasant, Soemmerring's copper pheasant.
G. L. Dowden, San Gabriel, Calif., western bullsnake.
Herbert Eaton, Chevy Chase, Md., 3 opossums.
W. D. Eliot, Washington, D. C., Florida gallinule.
Eugene Ferson, Washington, D. C., 2 common iguanas.
Firestone Rubber Plantations, through George Seibold, Monrovia, Liberia, African leopard, chimpanzee.
Mr. and Mrs. C. O. Fisher, Brentwood, Md., 2 cardinals.
A. T. Ford, Washington, D. C., red fox.
M. B. Foster, Orlando, Fla., worm snake, yellow-lipped snake.
Marty Gallagher, Washington, D. C., raccoon.
Arthur Garden, Washington, D. C., woodchuck or groundhog.
Joseph Gatti, Washington, D. C., blue jay.
Mr. Gaw, Washington, D. C., great white heron.
Miss Virginia Glass, Spring Lake, N. J., barred owl.
C. S. Goetz, Washington, D. C., yellow-naped parrot.
L. W. Gordon, Washington, D. C., 2 woodchucks or groundhogs.
Clarence L. Green, Cortland, N. Y., 4 garter snakes.
Gude Brothers, Florists, Washington, D. C., alligator.
Miss Mary Hamilton, Washington, D. C., grass paroquet.
H. H. Harland, Washington, D. C., sparrow hawk.
Louis A. Harris, Takoma Park, Md., albino squirrel.
Mrs. A. Hayden, Washington, D. C., alligator.
Charles Henderson, Concord, Mass., raccoon.
G. B. Howard, Washington, D. C., snapping turtle.
Mrs. W. W. Hughes, Washington, D. C., alligator.
H. N. Hunter, Washington, D. C., flying squirrel.
Laine Ilgenfritz, Washington, D. C., alligator.

Mrs. Ingham, Arlington, Va., kinkajou.
H. W. Irwin, Arlington, Va., white-throated capuchin.
W. T. Jewell, Arlington, Va., 4 skunks.
Ellis S. Joseph, New York City, 6 long-tailed finches.
W. A. Kearney, Washington, D. C., red fox.
Olive Kinsman, Silver Spring, Md., 5 skunks.
Mrs. F. C. Kleindeinst, Washington, D. C., rabbit, guinea pig.
Albert Koontz, Washington, D. C., black widow spider.
Mrs. J. R. Kump, Washington, D. C., alligator.
John Landrum, East Radford, Va., black mallard.
David Lawson, Washington, D. C., nighthawk.
Otto M. Locke, New Braunfels, Tex., 50 horned lizards, 10 scaly lizards.
C. E. Loomis, Washington, D. C., yellow-naped parrot.
Joseph N. Lowe, Washington, D. C., 4 skunks.
Richard Lowe, Chevy Chase, Md., ferret.
P. D. Lowell, Chevy Chase, Md., 3 barn owls.
Carl Lutz, Washington, D. C., sparrow hawk.
Howard Maben, Washington, D. C., coyote.
Charles T. Malone, Somerset, Md., 3 flying squirrels.
L. R. Mark, Washington, D. C., rhesus monkey.
Raymond Martin, Washington, D. C., alligator.
Mrs. Marx, Washington, D. C., small bird.
J. McDonald, Washington, D. C., Brazilian cardinal.
Mrs. O. McNey, Bethesda, Md., 2 guinea pigs.
George P. Meade, Gramercy, La., copperhead snake, DeKay's snake, smooth-scaled green snake, rough-scaled green snake, 3 Holbrook's king snakes, 3 hog-nosed snakes, 2 water snakes.
Bob Morgan, Miami, Fla., 2 alligators.
E. T. Morrison, Hanover, Va., gray fox.
Museum of Vertebrate Zoology, through Dr. Joseph Grinnell, D. H. Johnson, and Dale Arvey, Berkeley, Calif., 2 Great Basin pocket mice, Nevada pocket mouse, kangaroo pocket mouse, 2 sagebrush chipmunks.
Miss Mildred Myers, Washington, D. C., alligator.
Miss Gladys Necker, Suitland, Md., white-throated capuchin.
Mr. Nees, Riverdale, Md., red fox.
New York Zoological Park, New York City, 2 dingos, South African spitting cobra, golden cobra, puff adder.
Col. Newbold Noyes, Washington, D. C., American black bear.
Robert Nye, Washington, D. C., red-tailed hawk.
Paramount Aquarium, through Mr. Danisch, New York City, 2 large-headed Chinese turtles.
Lieut. E. M. Perkins, Washington, D. C., coyote.
Philadelphia Zoological Garden, Philadelphia, Pa., 6 European vipers.
G. Phillips, Washington, D. C., woodchuck or groundhog.
James Phillips, Golden Hill, Md., American white-fronted goose.
G. H. Pollock, Washington, D. C., banded rattlesnake.
Ramadi Bunnay Rajamatri, Washington, D. C., small turtle.
Raymond Rapp, Washington, D. C., 2 Pekin ducks.
Wm. E. Reeser, Bay Ridge, Md.. black snake.
Lawrence Reid, Langley, Va., American barn owl.
Mrs. Mabel T. Reid, Washington, D. C., titi monkey.
Lowry Riggs, Rockville, Md., spur-winged goose, toucanette.

Ralph C. Ringler, Grafton, W. Va., barred owl.
Mrs. R. C. Roberts, Chevy Chase, Md., opossum.
Mr. Rogers, Washington, D. C., Bonaparte's weasel.
Buddy Roland, Washington, D. C., opossum.
President Franklin D. Roosevelt, The White House, 2 East African hedgehogs.
Paul Rose, Washington, D. C., black snake.
Louis Ruhe, Inc., New York City, slender-billed cockatoo, 2 Chilean flamingoes.
Mrs. B. F. Schoff, Washington, D. C., woodchuck or groundhog.
Carolyn Sheldon, Woodstock, Va., 8 Eastern chipmunks.
Fred Simpich, Washington, D. C., nine-banded armadillo.
Mrs. G. B. Smith, Washington, D. C., zebra finch, orange-cheeked waxbill, society finch.
R. N. Smith, Washington, D. C., green guenon.
"Smoki People," through Paxson C. Hayes and G. C. Barnes, Prescott, Ariz., 5 Western bullsnakes, 2 red rattlesnakes, 2 Mexican rattlesnakes.
Prof. E. L. Strickland, Canal Port, Fla., scarlet snake.
D. R. Strohl, Arlington, Va., 2 Pekin ducks.
B. T. Tarman, Washington, D. C., American magpie.
Texas Cooperative Wildlife Service, through John Wood and H. R. Siegler. Huntsville, Tex., 2 nine-banded armadillos.
Henry Trefflich, Inc., New York City, spider monkey.
Mrs. Trundle, Washington, D. C., blue-fronted parrot.
U. S. Biological Survey, through O. J. Murie, Seattle, Wash., 3 California murre, tufted puffin; National Bison Range, Moiese, Mont., American bison, albino bison; Rodent and Predatory Animal Control Division, Washington, D. C., meadow mouse, Lemming mouse, jumping mouse, red-backed mouse, white-footed mouse, pine mouse; Chandler R. Young, Lacreek Migratory Waterfowl Refuge, Martin, S. D., 2 minks.
U. S. National Park Service, through A. E. Borell, Albuquerque, N. Mex., 3 spotted ground squirrels.
Miss Anna Van Bibbler, Washington, D. C., guinea pig.
E. G. Vaughn, Salisbury, Md., 3 red-shouldered hawks.
Adolph L. Vlasski, Washington, D. C., 2 Texas armadillos.
H. C. Walford, Washington, D. C., domestic goose.
Ernest P. Walker, Washington, D. C., western bullsnake, 2 dwarf rabbits, 4 long-tailed tree mice, grasshopper mouse, 8 salamanders, garter snake.
Miss Edith H. Ward, Washington, D. C., green pheasant.
Miss Mary Warren, Washington, D. C., 2 false chameleons.
Miss Leola Washburn, Washington, D. C., eastern mole.
Washington Humane Society, Washington, D. C., robin.
Mrs. E. Weeks, Washington, D. C., alligator.
R. Wheat, Erlanger, N. C., flying squirrel.
C. T. White, Norfolk, Va., golden eagle.
F. S. White, Washington, D. C., common boa.
K. C. White, Washington, D. C., 2 barn owls.
Miss L. Wilkins, Washington, D. C., alligator.
Billy Williams, Washington, D. C., alligator.
Mrs. Robert C. Winmill, Warrenton, Va., Chapman's zebra.
Fred J. Young, Washington, D. C., skunk.
Donor unknown, 3 Harris antelope squirrels.

Births.—There were 34 mammals born and 30 birds hatched in the Park during the year. Among the birds were two jackass penguins.

MAMMALS

Scientific name	Common name	Number
Ammotragus lervia	Aoudad	3
Axis axis	Axis deer	1
Bison bison	American bison	2
Bos frontalis	Gayal	1
Canis rufus	Texas red wolf	4
Capromys pilorides	Hutia	4
Cervus elaphus	Red deer	5
Choeropsis liberiensis	Pigmy hippopotamus	1
Dama dama	Fallow deer	2
Equus quagga chapmani	Chapman's zebra	1
Felis onca	Jaguar	1
Hemitragus jemlahicus	Tahr	1
Lama glama	Llama	2
Macaca mordax	Javan macaque	1
Oryx beisa annectens	Ibean beisa oryx	1
Ovis europaeus	Mouflon	1
Sika nippon	Japanese deer	2
Taurotragus oryx	Eland	1

BIRDS

Anas domestica	Pekin duck	3
Anas rubripes	Black or dusky mallard	9
Branta canadensis	Canada goose	5
Larus novaehollandiae	Silver gull	11
Spheniscus demersus	Jackass penguin	2

Exchanges.—Among important specimens received in exchange from various sources were: One South American lesser tiger cat, one hairy armadillo, one tamarin, three smooth-clawed frogs, one pair dwarf cavies, one giant anteater, and one Sumatran gibbon.

Purchases.—Important purchases during the year were a pair of Pacific otters, a pair of ring-tailed lemurs, a pair of cheetas, a pair of Tasmanian devils, a red ouakari monkey, a pair of brush-tailed porcupines, two pottos, one gaboon viper, two tree vipers, one leaf toad, and one giant frog (*Rana goliath*), the first of its kind ever exhibited at the Park.

REMOVALS

Deaths.—The death on August 12, 1937, of "Babe," the Indian elephant presented to the Park in May 1934 by Ringling Brothers-Barnum and Bailey Circus, removed a famous animal with a record of 51 years with circuses, and more than 3 years in the Zoo. Other major losses included two Asiatic tapirs, one Bactrian camel, and a Steller's sea lion.

All specimens of scientific value that died during the year were sent to the National Museum.

ANIMALS IN COLLECTION THAT HAD NOT PREVIOUSLY BEEN EXHIBITED

MAMMALS

Scientific name	Common name
Arctonyx collaris	Hog badger.
Callosciurus piceus	Beautiful squirrel.
Charronia flavigula henricii	Asiatic marten.
Cuon javanicus sumatrensis	Sumatran wild dog.
Cynopithecus tonsus	Black macaque.
Jaculus jaculus	Egyptian jerboa.
Mico rufimanus	Tamarin or black marmoset.
Micraonyx leptonyx	Small-clawed otter.
Mystax mystax	White-lipped tamarin.
Nycticebus coucang	Slow loris.
Presbytis pyrrhus	Javan langur or lotong.
Ratufa bicolor	Javan giant squirrel.
Ratufa macroura	Ceylon giant squirrel.
Thecurus sumatrae	Sumatran brush-tailed porcupine.
Tomeutes notatus	Javan brown squirrel.
Tupaia siaca	Tree shrew.

BIRDS

Aplonis chalybea	Glossy aplonis.
Berenicornis comatus	Long-crested hornbill.
Calyptorhynchus magnificus	Banksian cockatoo.
Chalcopsitta atra	Black lory.
Ducula pinon	Red-eyed fruit pigeon.
Fregata ariel	Lesser frigate bird.
Ibis cinereus	Malay stork.
Irena puella	Fairy blue bird.
Ketupa ketupu	Malay fishing owl.
Lamprotreron jambu	Pink-headed fruit pigeon.
Lophura diardi	Siamese crested fire-back pheasant.
Lophura rubra	Malayan fire-back pheasant.
Manucodia atra	Black manucode.
Megapodius freycineti	Molucca megapode.
Mesia argentauris	Silver-eared mesia.
Myristicivora bicolor	Pied imperial pigeon.
Oriolas chinensis	Sumatran oriole.
Podargus strigoides	Tawny frogmouth.
Pseudeos fuscata	Dusky lory.
Psittrichas fulgidas	Vulturine parrot.
Ptilinopus humeralis	Purple-shouldered fruit pigeon.
Ptilinopus regina	Purple-capped fruit pigeon.
Ptilonorhynchus violaceus	Satin bower bird.
Rallus sp	Sumatran rail.
Spilornis nipalensis	Serpent eagle.
Tanygnathus muelleri	Mueller's parrot.
Uria aalge californica	California murre.

REPTILES

Acanthosaura armata	Armed tree lizard.
Alligator sinensis	Chinese alligator.
Batagur baska	Baska turtle.
Boiga cynodon	Cat-eyed tree snake.
Denisonia superba	Australian copper-head snake.
Geoclemys subtrijuga	Siamese field turtle.
Geomyda spinosa	Spiny hill tortoise.
Notechis scutatus	Australian tiger snake.
Physignathus cocincinus	Siamese water dragon.
Python amethystinus	Amethystine python.
Rana goliath	Giant frog.
Trimeresurus sp	Palm viper.
Trionyx cartilagineus	Asiatic soft-shelled turtle.

Statement of accessions

Class	Received from National Geographic-Smithsonian Institution East Indies Expedition	Presented	Born	Received in exchange	Purchased	On deposit	Total
Mammals	121	118	34	16	18	9	316
Birds	649	74	30	13	24	8	798
Reptiles	108	167		25	28	5	333
Amphibians	1	10		3	10		24
Fishes					18		18
Arachnids		3					3
Mollusks					5		5
Total	879	372	64	57	103	22	1,497

Summary

Animals on hand July 1, 1937	2,342
Accessions during the year	1,497
Total animals in collection during year	3,839
Removal from collection by death, exchange, and return of animals on deposit	1,085
In collection June 30, 1938	2,754

Status of collection

Class	Species	Individuals	Class	Species	Individuals
Mammals	239	699	Arachnids	2	7
Birds	367	1,264	Insects	1	100
Reptiles	134	432	Mollusks	1	6
Amphibians	28	129			
Fishes	21	117	Total	793	2,754

ANIMALS IN THE NATIONAL ZOOLOGICAL PARK, JUNE 30, 1938

Mammals

MARSUPIALIA

		Number
Didelphidae:		
Didelphis virginiana	Opossum	4
Metachirus opossum	Zorro or banana opossum	1
Dasyuridae:		
Dasyurus viverrinus	Viverrine native cat	1
Sarcophilus ursinus	Tasmanian devil	2
Phalangeridae:		
Petaurus breviceps	Lesser flying phalanger	3
Trichosurus vulpecula	Vulpine opossum	1
Macropodidae:		
Dendrolagus inustus	Tree kangaroo	2
Dendrolagus ursinus × *D. inustus*	Hybrid tree kangaroo	1

INSECTIVORA

Erinaceidae:		
Atelerix hindei	East African hedgehog	2

CARNIVORA

Felidae:		
Acinonyx jubatus	Cheeta	2
Felis concolor	Puma	5
Felis leo	Lion	6
Felis ocreata	African wild cat	1
Felis onca	Jaguar	3
	Black jaguar	2
Felis pardalis	Ocelot	1
Felis pardinoides	Lesser tiger cat	1
Felis pardus	Leopard	5
	Black leopard	3
Felis pardus suahelicus	East African leopard	1
Felis tigris longipilis	Siberian tiger	2
Felis tigris sondaicus	Sumatran tiger	4
Lynx baileyi	Bailey's lynx	1
Lynx caracal	Caracal	1
Lynx rufus	Bay lynx	5
Neofelis nebulosa	Clouded leopard	1
Profelis temmincki	Bay or golden cat	3
Viverridae:		
Arctictis binturong	Binturong	5
Civettictis civetta	Civet	1
Genetta dongalana neumanni	Neumann's genet	1
Moschothera megaspila	Civet	2
Paradoxurus hermaphrodytus	Small-toothed palm civet	4
Hyaenidae:		
Crocuta crocuta germinans	East African spotted hyena	1
Hyaena brunnea	Brown hyena	2

		Number
Canidae:		
Canis dingo	Dingo	2
Canis latrans	Coyote	16
	Albino coyote	3
Canis latrans × domestica	Coyote and dog hybrid	1
Canis lupus lycaon	Timber wolf	2
Canis lupus nubilus	Wolf	3
Canis lupus nubilus × domesticus	Wolf and dog hybrid	5
Canis rufus	Texan red wolf	1
Chrysocyon jubata	Maned wolf	7
Cuon javanicus sumatrensis	Sumatran wild dog	1
Urocyon cinereoargenteus	Gray fox	1
Vulpes fulva	Red fox	9
Procyonidae:		
Nasua narica	Gray coatimundi	4
Potos flavus	Kinkajou	2
Procyon cancrivorus	Crab-eating raccoon	1
Procyon lotor	Raccoon	12
	Albino raccoon	1
	Black raccoon	5
Bassariscidae:		
Bassariscus astutus	Ring-tail or cacomistle	1
Mustelidae:		
Arctonyx collaris	Hog badger	2
Charronia flavigula henricii	Asiatic marten	1
Galictis barbara barbara	White tayra	2
Lutra canadensis vaga	Florida otter	3
Mellivora capensis	Ratel	1
Mephitis nigra	Skunk	12
Micraonyx leptonyx	Small-clawed otter	1
Mustela eversmanni	Ferret	3
Mustela noveboracensis	Weasel	1
Mustela vison vison	Mink	1
Spilogale ambarvalis	Florida spotted skunk	1
Ursidae:		
Euarctos americanus	American black bear	5
Euarctos emmonsii	Glacier bear	1
Helarctos malayanus	Malay or sun bear	1
Thalarctos maritimus	Polar bear	2
Thalarctos maritimus × Ursus gyas	Hybrid bear	3
Ursus arctos	European brown bear	3
Ursus gyas	Alaska Peninsula brown bear	4
Ursus kidderi	Kidder's bear	1
Ursus middendorffi	Kodiak bear	4
Ursus sitkensis	Sitka brown bear	3
Ursus thibetanus	Himalayan bear	3

PINNIPEDIA

Otariidae:		
Zalophus californianus	California sea lion	2
Phocidae:		
Phoca *richardii*	Pacific harbor seal	3

PRIMATES

		Number
Lemuridae:		
Lemur catta	Ring-tailed lemur	2
Nycticebus coucang	Slow loris	5
Perodicticus potto	Potto	1
Perodicticus sp	Potto	1
Callitrichidae:		
Leontocebus rosalia	Lion-headed or golden marmoset	3
Mico argentata	Black-tailed marmoset	2
Mystax mystax	White-lipped tamarin	1
Saimiridae:		
Saimiri sciureus	Titi or squirrel monkey	1
Cebidae:		
Cacajao rubicundus	Red ouakari	1
Cebus apella	Brown capuchin	1
Cebus capucinus	White-throated capuchin	5
Cebus fatuella	Weeping capuchin	3
Cebus sp	Brown capuchin	2
Cercopithecidae:		
Cercocebus fuliginosus	Sooty mangabey	5
Cercopithecus aethiops roloway	Roloway monkey	1
Cercopithecus aethiops sabaeus	Green guenon	6
Cercopithecus albigularis	Syke's guenon	2
Cercopithecus diana	Diana monkey	1
Cercopithecus neglectus	De Brazza's guenon	1
Cercopithecus petaurista	Lesser white-nosed guenon	2
Cercopithecus pygerythra	Vervet guenon	1
Colobus polycomos caudatus	White-tailed guereza	1
Colobus polycomos polycomos	White-tailed colobus	1
Macaca fuscata	Japanese monkey	2
Macaca lasiotis	Chinese macaque	3
Macaca mordax	Javan macaque	13
Macaca mulatta	Rhesus monkey	10
Macaca nemestrina	Pig-tailed monkey	8
Macaca silenus	Wanderoo monkey	2
Macaca sinica	Bonnet monkey	1
Magus maurus	Moor monkey	4
Mandrillus leucophaeus	Drill	1
Mandrillus sphinx	Mandrill	3
Papio comatus	Chacma	2
Papio papio cynocephalus	East African baboon	1
Papio papio papio	West African baboon	1
Presbytis pyrrhus	Javan langur or lotong	1
Theropithecus gelada	Gelada baboon	1
Hylobatidae:		
Hylobates agilis	Sumatran gibbon	1
Hylobates lar pileatus	White-handed gibbon	3
Symphalangus syndactylus	Siamang gibbon	1
Pongidae:		
Pan satyrus	Chimpanzee	2
Pongo abelii	Sumatran orangutan	2
Pongo pygmaeus	Bornean orangutan	1

RODENTIA

		Number
Sciuridae:		
Ammospermophilus harrisi	Harris antelope squirrel	3
Callosciurus melanops	Sumatran tricolored squirrel	2
Callosciurus piceus	Beautiful squirrel	1
Callospermophilus saturatus	Mantled ground squirrel	2
Citellus mexicanus parvidens	Rio Grande ground squirrel	1
Citellus richardsonii	Richardson ground squirrel	8
Citellus richardsonii elegans	Picket-pin gopher	1
Citellus spilosoma	Spotted ground squirrel	3
Citellus tridecemlineatus	Flag squirrel	6
Cynomys ludovicianus	Prairie dog	10
Eutamias amoenus amoenus	Klamath chipmunk	1
Glaucomys volans	Flying squirrel	7
Marmota flaviventris	Marmot or whistler	2
Marmota monax	Woodchuck or groundhog	12
	Albino woodchuck or groundhog	1
Ratufa bicolor	Javan giant squirrel	1
Sciurus finlaysoni	Lesser white squirrel	8
Sciurus hoffmani subsp	Hoffman's squirrel	2
Sciurus niger	Fox squirrel	5
Tamias striatus	Eastern chipmunk	2
Tamiasciurus hudsonicus	Red squirrel	1
Tomeutes notatus	Javan brown squirrel	2
Geomyidae:		
Thomomys douglasii yelmensis	Yelm pocket gopher	1
Heteromyidae:		
Dipodomys deserti	Desert kangaroo rat	1
Dipodomys merriami	Merriam kangaroo rat	2
Microdipodops pallidus	Gnome or kangaroo mouse	1
Perognathus hispidus	Hispid pocket mouse	1
Perognathus longimembris	Nevada pocket mouse	1
Perognathus parvus	Great Basin pocket mouse	1
Perognathus penicilliatus	Desert pocket mouse	1
Jaculidae:		
Jaculus jaculus	Egyptian jerboa	4
Castoridae:		
Castor canadensis	Beaver	1
Cricetidae:		
Neotoma floridana attwateri	Round-tailed wood rat	2
Onychomys sp	Grasshopper mouse	1
Peromyscus leucopus	White-footed mouse	3
Sigmodon hispidus	Cotton rat	9
Zapus hudsonius	Jumping mouse	1
Rhizomyidae:		
Nyctocleptes sumatrensis	Bamboo rat	1
Muridae:		
Cricetomys gambianus	Gambia pouched rat	2
Hystricidae:		
Acanthion brachyurum	Malay porcupine	5
Atherurus africana	West African brush-tailed porcupine.	2
Hystrix galeata	East African porcupine	2
Thecurus sumatrae	Sumatran porcupine	1

		Number
Erethizontidae:		
Coendou prehensilis	Prehensile-tailed porcupine	1
Capromyidae:		
Capromys pilorides	Hutia	8
Cuniculidae:		
Cuniculus paca virgatus	Central American paca	2
Dasyproctidae:		
Dasyprocta croconota prymnolopha	Agouti	2
Myoprocta sp	Tailed agouti	1
Caviidae:		
Cavia porcellus	Domestic guinea pig	10
Dolichotis magellanica	Patagonian cavy	1
Pediolagus salinicola	Dwarf cavy	3
Hydrochoeridae:		
Hydrochoerus hydrochoerus	Capybara	1

LAGOMORPHA

Leporidae:		
Lepus americanus	Varying hare or snowshoe rabbit	1
Oryctolagus cuniculus	Domestic rabbit	2
	Angora rabbit	1

ARTIODACTYLA

Bovidae:		
Ammotragus lervia	Aoudad	11
Anoa depressicornis	Anoa	2
Antilope cervicapra	Black buck or Indian antelope	1
Bibos gaurus	Gaur	2
Bison bison	American bison	24
Bos frontalis	Gayal	5
Bos indicus	Zebu	4
Boselaphus tragocamelus	Nilgai	1
Bubalus bubalis	Indian buffalo	1
Capra sibirica	Siberian ibex	1
Connochaetes gnu	White-tailed gnu	2
Connochaetes taurinus albojubatus	White-bearded gnu	2
Hemitragus jemlahicus	Tahr	5
Onotragus lechee	Lechee antelope	1
Oryx beisa annectens	Ibean beisa oryx	2
Ovis europaeus	Mouflon	3
Poephagus grunniens	Yak	3
Pseudois nahura	Bharal or blue sheep	2
Synceros caffer	African buffalo	2
Taurotragus oryx	Eland	3
Antilocapridae:		
Antilocapra americana	Pronghorn antelope	2
Cervidae:		
Axis axis	Axis deer	8
Cervus canadensis	American elk	2
Cervus duvaucellii	Barasingha deer	3
Cervus elaphus	European red deer	14
Cervus xanthopygus	Bedford deer	2
Dama dama	Fallow deer	8
	White fallow deer	15

		Number
Cervidae—Continued.		
Muntiacus muntjak	Barking or rib-faced deer	1
Muntiacus sinensis	Chinese rib-faced deer	1
Odocoileus costaricensis	Costa Rican deer	2
Odocoileus virginianus	Virginia deer	3
Rusa moluccensis	Molucca deer	2
Rusa unicolor	Sambur deer	1
Sika nippon	Japanese deer	8
Tragulidae:		
Tragulus javanicus	Javan mouse deer	1
Giraffidae:		
Giraffa camelopardalis	Nubian giraffe	4
Camelidae:		
Lama glama	Llama	7
Lama huanacus	Guanaco	2
Tayassuidae:		
Pecari angulatus	Collared peccary	2
Tayassu pecari	White-lipped peccary	2
Suidae:		
Babirussa alfurus	Babirussa	3
Phacochoerus aethiopicus massaicus	East African warthog	3
Sus scrofa	European wild boar	1
Hippopotamidae:		
Choeropsis liberiensis	Pigmy hippopotamus	3
Hippopotamus amphibius	Hippopotamus	1

PERISSODACTYLA

Equidae:		
Equus grevyi	Grevy's zebra	1
Equus grevyi-asinus	Zebra-ass hybrid	1
Equus grevyi-caballus	Zebra-horse hybrid	1
Equus onager	Asiatic wild ass or kiang	2
Equus przewalskii	Mongolian wild horse	3
Equus quagga chapmani	Chapman's zebra	10
Equus zebra	Mountain zebra	2
Tapiridae:		
Acrocodia indica	Asiatic tapir	1
Tapirella bairdii	Baird's tapir	1
Tapirus terrestris	Brazilian tapir	1
Rhinocerotidae:		
Diceros bicornis	Black rhinoceros	1

PROBOSCIDEA

Elephantidae:		
Elephas sumatranus	Sumatran elephant	1
Loxodonta africana oxyotis	African elephant	1

EDENTATA

Choloepodidae:		
Choloepus didactylus	Two-toed sloth	3
Dasypodidae:		
Dasypus novemcinctus	Nine-banded armadillo	1
Euphractus sexcinctus	Six-banded armadillo	1
Myrmecophagidae:		
Myrmecophaga jubata	Giant anteater	1

Birds

STRUTHIONIFORMES

		Number
Struthionidae:		
Struthio camelus	South African ostrich	1

RHEIFORMES

Rheidae:		
Rhea americana	Common rhea or nandu	1

CASUARIIFORMES

Casuariidae:		
Casuarius benneti	Bennett's cassowary	1
Casuarius sp. (young)	Cassowary	5
Casuarius unappendiculatus	Single-wattled cassowary	1
Dromiceiidae:		
Dromiceius novaehollandiae	Common emu	1

SPHENISCIFORMES

Spheniscidae:		
Spheniscus demersus	Jackass penguin	5

PELECANIFORMES

Pelecanidae:		
Pelecanus californicus	California brown pelican	2
Pelecanus conspicillatus	Australian pelican	1
Pelecanus erythrorhynchos	American white pelican	6
Pelecanus erythrorhynchos × *P. occidentalis*	Hybrid pelican	1
Pelecanus occidentalis	Brown pelican	4
Pelecanus onocrotalus	European pelican	2
Pelecanus roseus	Rose-colored pelican	2
Sulidae:		
Morus bassanus	Gannet	1
Sula granti	Blue-footed booby	1
Phalacrocoracidae:		
Nannopterum harrisi	Flightless cormorant	2
Phalacrocorax auritus albociliatus	Farallon cormorant	2
Phalacrocorax auritus floridanus	Florida cormorant	1
Anhingidae:		
Anhinga anhinga	Anhinga	1
Fregatidae:		
Fregata ariel	Lesser frigate bird	2

CICONIIFORMES

Ardeidae:		
Ardea herodias	Great blue heron	1
Ardea herodias × *A. occidentalis*	Hybrid heron	2
Ardea occidentalis	Great white heron	1
Casmerodius albus egretta	American egret	1
Nycticorax nycticorax naevius	Black-crowned night heron	25
Cochleariidae:		
Cochlearius cochlearius	Boatbill heron	3
Balaenicipitidae:		
Balaeniceps rex	Shoebill stork	3

		Number
Scopidae:		
Scopus umbretta	Hammerhead	1
Ciconiidae:		
Dissoura episcopus	Woolly-necked stork	1
Ephippiorhynchus senegalensis	Saddle-billed stork	1
Ibis cinereus	Malay stork	2
Jabiru mycteria	Jabiru	2
Leptoptilus crumeniferus	Marabou	1
Leptoptilus dubius	Indian adjutant	1
Leptoptilus javanicus	Lesser adjutant	2
Mycteria americana	Wood ibis	1
Threskiornithidae:		
Ajaia ajaja	Roseate spoonbill	1
Guara alba	White ibis	3
Guara alba × *G. rubra*	Hybrid ibis	1
Guara rubra	Scarlet ibis	2
Threskiornis aethiopica	Sacred ibis	2
Threskiornis melanocephala	Black-headed ibis	1
Phoenicopteridae:		
Phoenicopterus chilensis	Chilean flamingo	8

ANSERIFORMES

Anatidae:		
Aix sponsa	Wood duck	13
Alopochen aegyptiacus	Egyptian goose	2
Anas domestica	Peking duck	15
Anas platyrhynchos	Mallard	26
Anas rubripes	Black or dusky mallard	1
Anas undulata	African yellow-billed duck	8
Anser albifrons	American white-fronted goose	3
Anser fabalis	Bean goose	2
Branta bernicla	Brant	3
Branta canadensis	Canada goose	9
Branta canadensis hutchinsii	Hutchin's goose	4
Branta canadensis minima	Cackling goose	4
Branta canadensis occidentalis	White-cheeked goose	18
Branta leucopsis	Barnacle goose	1
Cairina moschata	Muscovy duck	3
Casarca variegata	Paradise duck	1
Cereopsis novaehollandiae	Cereopsis or Cape Barren goose	1
Chen atlantica	Snow goose	7
Chen caerulescens	Blue goose	9
Chloephaga leucoptera	Magellan goose	1
Cygnopsis cygnoides	Chinese goose	2
Cygnus columbianus	Whistling swan	3
Cygnus olor	Mute swan	1
Dafila acuta	Pintail duck	6
Dafila bahamensis	Bahaman pintail	1
Dafila acuta × *D.* sp	Pintail hybrid	1
Dendrocygna arborea	Black-billed duck	4
Dendrocygna autumnalis	Black-bellied tree duck	4
Dendrocygna viduata	White-faced tree duck	1
Mareca americana	Bald pate	3
Nyroca collaris	Ring-neck duck	1

		Number
Anatidae—Continued.		
Philacte canagica	Emperor goose	11
Plectropterus gambensis	Spur-winged goose	2
Querquedula cyanoptera	Cinnamon teal	1
Querquedula discors	Blue-winged teal	1
Sarkidiornis melanota	Comb duck	1
FALCONIFORMES		
Cathartidae:		
Cathartes aura	Turkey vulture	3
Cathartes aura × *Coragyps atratus*	Black Carolina and turkey vulture hybrid.	1
Coragyps atratus	Black vulture	1
Gymnogyps californianus	California condor	3
Vultur gryphus	South American condor	1
Accipitridae:		
Aegypius monachus	Cinereous vulture	1
Aquila chrysaetos	Golden eagle	2
Buteo borealis	Red-tailed hawk	3
Buteo lineatus	Red-shouldered hawk	3
Buteo platypterus	Broad-winged hawk	1
Buteo swainsoni	Swainson's hawk	1
Gypaetus barbatus grandis	Lammergeyer	1
Gyps rueppelli	Ruppell's vulture	1
Haliastur indus	Malay brahminy kite	3
Haliaeetus leucocephalus	Bald eagle	20
Milvus migrans	Yellow-billed kite	1
Pandion haliaetus carolinensis	Osprey or fish hawk	2
Stephanoaetus coronatus	Crowned hawk eagle	1
Torgos tracheliotus	African eared-vulture	1
Uroaetus audax	Wedge-tailed eagle	1
Falconidae:		
Falco columbarius	Pigeon hawk	1
Falco sparverius	Sparrow hawk	3
Polihierax semitorquatus	African pigmy falcon	1
Polyborus cheriway	Audubon's caracara	2
Polyborus plancus	South American caracara	1
GALLIFORMES		
Megapodiidae:		
Megapodius freycineti	Molucca megapode	2
Cracidae:		
Crax rubra	Panama curassow	1
Mitu mitu	Razor-billed curassow	1
Mitu salvini	Salvin's curassow	1
Phasianidae:		
Alectoris graeca	Chukar partridge	2
Argusianus argus	Argus pheasant	2
Catreus wallichii	Cheer pheasant	1
Chrysolophus amherstiae	Lady Amherst's pheasant	1
Chrysolophus amherstiae × *Syrmaticus reevesi*	Hybrid pheasant	1
Chrysolophus pictus	Golden pheasant	4
Colinus virginianus	Bobwhite	1

Phasianidae—Continued.		Number
Coturnix coturnix	Migratory quail	26
Coturnix japonica	Asiatic migratory quail	1
Crossoptilon mantchuricum	Manchurian pheasant	1
Excalfactoria chinensis	Blue-breasted button quail	8
Gallus gallus	Jungle fowl	3
Gallus gallus × *Numida galeata*	Chicken × guinea fowl hybrid	2
Gennaeus lineatus	Lineated pheasant	3
Gennaeus nycthemerus	Silver pheasant	2
Hierophasis swinhoei	Swinhoe's pheasant	1
Lophophorus impeyanus	Himalayan Impeyan pheasant	2
Lophura diardi	Siamese crested fire-back pheasant	1
Lophura rubra	Malayan fire-back pheasant	1
Pavo cristatus	Blue peafowl	5
Pavo muticus	Green peafowl	2
Phasianus torquatus	Ring-necked pheasant	2
	White ring-necked pheasant	2
Phasianus torquatus formosanus	Formosan ring-necked pheasant	1
Phasianus versicolor	Green pheasant	4
Syrmaticus reevesi	Reeve's pheasant	2

GRUIFORMES

Gruidae:		
Anthropoides virgo	Demoiselle crane	2
Antigone australasiana	Australian crane	1
Balearica pavonina	West African crowned crane	1
Balearica regulorum gibbericeps	East African crowned crane	1
Grus canadensis canadensis	Little brown crane	1
Grus canadensis tabida	Sandhill crane	1
Grus leucauchen	White-naped crane	1
Grus leucogeranus	Siberian crane	2
Psophiidae:		
Psophia crepitans	Gray-backed trumpeter	1
Rallidae:		
Gallinula chloropus cachinnans	Florida gallinule	2
Gallinula chloropus sub. sp	Sumatran gallinule	3
Limnocorax flavirostra	African black rail	3
Porphyrio melanotus	New Zealand mud hen	1
Porphyrio poliocephalus	Gray-headed porphyrio	2
Rallus sp	Sumatran rail	3
Eurypygidae:		
Eurypyga helias	Sun bittern	2
Otididae:		
Otis cafra	Denham's bustard	1
Otis caffra jacksoni	Jackson's bustard	1

CHARADRIIFORMES

Haematopodidae:		
Haematopus ostralegus	European oyster catcher	2
Charadriidae:		
Belonopterus cayennensis	South American lapwing	1
Sarciophorus tectus	Black-headed plover	1
Scolopacidae:		
Philomachus pugnax	Ruff	1

		Number
Laridae:		
Larus argentatus	Herring gull	1
Larus delawarensis	Ring-billed gull	2
Larus glaucescens	Glaucous-winged gull	1
Larus novaehollandiae	Silver gull	65
Larus occidentalis	Western gull	1
Larus ridibundus	European gull	1

COLUMBIFORMES

Pteroclidae:		
Pterocles orientalis	Oriental sandgrouse	2
Columbidae:		
Caloenas nicobarica	Nicobar pigeon	5
Chalcophaps indica	Emerald dove	4
Columba fulviventris	Forest dove	1
Columba leuconota	Tibetan pigeon	2
Columba palumbus	Wood pigeon	1
Columba livia (domestic)	Archangel pigeon	2
Columba livia (domestic)	Fan-tailed pigeon	5
Dendrophassa vernans	Sumatran fruit pigeon	4
Ducula aenea	Green imperial pigeon	4
Ducula pinon	Red-eyed fruit pigeon	4
Gallicolumba luzonica	Bleeding heart dove	10
Goura sclaterii	Sclater's crowned pigeon	5
Goura victoria	Victoria crowned pigeon	5
Lamprotreron jambu	Pink-headed fruit pigeon	8
Leptotila rufaxilla	Scaled pigeon	2
Macropygia unchall	Cuckoo dove	11
Muscadivores paulina	Celebian imperial pigeon	4
Myristicivora bicolor	Pied imperial pigeon	5
Ptilinopus humeralis	Purple-shouldered fruit dove	2
Ptilinopus regina	Purple-capped fruit dove	5
Streptopelia chinensis	Asiatic collared dove	28
Streptopelia risoria	Ring-necked dove	7
Streptopelia senegalensis	East African ring-necked dove	1
Turtur risorius	Turtle dove	1
Zenaidura macroura macroura	West Indian dove	1

PSITTACIFORMES

Psittacidae:		
Agapornis lilianae	Nyassa lovebird	1
Amazona albifrons	White-fronted parrot	3
Amazona amazonica	Orange-winged parrot	2
Amazona arausiaca	Bouquet's parrot	1
Amazona auropalliata	Yellow-naped parrot	10
Amazona bodini	Red-fronted parrot	1
Amazona festiva	Festive parrot	1
Amazona leucocephala	Cuban parrot	2
Amazona ochrocephala	Yellow-headed parrot	9
Amazona ochroptera	Yellow-shouldered parrot	3
Amazona oratrix	Double yellow-head parrot	6
Amazona viridigenalis	Red-crowned parrot	1
Anodorhynchus hyacinthinus	Hyacinthine macaw	1
Aprosmictus amboinensis	Amboina lory	1
Ara ararauna	Yellow and blue macaw	3

Psittacidae—Continued.		Number
Ara chloroptera	Red and yellow macaw	1
Ara macao	Red, yellow, and blue macaw	3
Ara maracana	Illiger's macaw	2
Ara militaria	Mexican green macaw	3
Ara severa	Severe macaw	1
Aratinga solstitialis	Yellow paroquet	1
Brotogeris jugularis	Tovi paroquet	2
Calyptorhynchus magnificus	Banksian cockatoo	1
Coracopsis nigra	Lesser vasa parrot	1
Cyanopsittacus spixi	Spix's macaw	2
Domicella garrula garrula	Red lory	11
Eclectus pectoralis	Eclectus parrot	2
Eolophus roseicapillus	Roseate cockatoo	2
Eos cyanogenia	Blue-eared lory	1
Eos rubra	Red lory	1
Eupsittula aurea	Golden-crowned paroquet	1
Eupsittula canicularis	Petz paroquet	1
Kakatoe alba	White-crested cockatoo	3
Kakatoe citrinocristata	Orange-crested cockatoo	1
Kakatoe galerita	Sulphur-crested cockatoo	4
Kakatoe leadbeateri	Leadbeater's cockatoo	2
Kakatoe moluccensis	Great red-crested cockatoo	2
Kakatoe sulphurea	Lesser sulphur-crested cockatoo	11
Kakatoe tenuirostris	Slender-billed cockatoo	1
Leptolophus novaehollandicus	Cockatiel	2
Loriculus galgulus	Hanging parrotlet	2
Lorius domicella	Rajah lory	2
Lorius lory	Blue-crowned lory	1
Melopsittacus undulatus	Grass paroquet	17
Microglossus aterrimus	Great black cockatoo	1
Myopsitta monachus	Quaker paroquet	1
Nandayus nanday	Nanday paroquet	1
Nestor notabilis	Kea	4
Pionites xanthomera	Amazonian caique	2
Pionus menstruus	Blue-headed parrot	1
Psittacula eupatria	Red-shouldered paroquet	5
Psittacula krameri	Kramer's paroquet	6
Psittacula longicauda	Long-tailed paroquet	3
Psittacula nepalensis	Nepalese paroquet	1
Psittacus erithacus	African gray parrot	2
Tanygnathus megalorhynchus	Great-billed parrot	1
Tanygnathus muelleri	Mueller parrot	1
Trichoglossus cyanogrammus	Green-naped lory	1
Trichoglossus haematod	Ceram lory	4
Trichoglossus nigrogularis	Blue-fronted lory	3
Trichoglossus novaehallandiae	Blue-bellied lory	1

CUCULIFORMES

Cuculidae:		
Centropus sinensis	Sumatran coucal	1
Eudynamis scolopaceus	Koel	2

STRIGIFORMES

		Number
Strigidae:		
Bubo virginianus	Great horned owl	7
Ketupa ketupu	Malay fishing owl	1
Otus asio	Screech owl	2
Strix varia	Barred owl	15

CAPRIMULGIFORMES

Caprimulgidae:		
Chordeiles minor	Nighthawk	2
Podargidae:		
Podargus strigoides	Tawny frogmouth	1

CORACIIFORMES

Alcedinidae:		
Dacelo gigas	Kookaburra	2
Halcyon pyrrhopygius	Red-backed kingfisher	2
Halcyon sanctus	Sacred kingfisher	6
Momotidae:		
Momotus momotus parensis	Motmot	1
Bucerotidae:		
Berenicornis comatus	Long-crested hornbill	1
Buceros rhinoceros	Rhinoceros hornbill	2
Bucorvus abyssinicus	Abyssinian ground hornbill	2
Dichoceros bicornis	Concave casque hornbill	2
Hydrocissa convexa	Pied hornbill	2
Rhyticeros plicatus	Plicated hornbill	1

PICIFORMES

Ramphastidae:		
Pteroglossus bitorquatus	Two-banded aracari	1
Ramphastos ariel	Ariel toucan	1
Ramphastos culminatus	White-breasted toucan	1
Ramphastos toco	Toco toucan	2
Selenidera culik	Guiana toucanette	1
Capitonidae:		
Ihereiceryx zeylandicus	Streaked barbet	2

PASSERIFORMES

Oriolidae:		
Oriolas chinensis	Sumatran oriole	3
Cotingidae:		
Chasmorhynchus nudicollis	Naked-throated bell-bird	2
Rupicola rupicola	Cock of the rock	1
Pittidae:		
Pitta brachyura	Indian pitta	1
Pitta moluscensis	Molucca pitta	2
Tyrannidae:		
Pitangus sulphuratus	Kiskadee flycatcher	2
Corvidae:		
Aphelocoma californica woodhousei	Woodhouse's jay	1
Calocitta formosa	Mexican magpie jay	1
Cissa chinensis	Chinese cissa	2

		Number
Corvidae—Continued.		
Corvus albus	White-breasted crow	2
Corvus brachyrhynchos	American crow	3
Corvus corax sinuatus	American raven	1
Corvus coronoides	Australian crow	2
Corvus cryptoleucus	White-necked raven	6
Corvus insolens	Indian crow	4
Cyanocitta cristata	Blue jay	2
Cyanocorax cyanopogon	White-naped jay	2
Gymnorhina hypoleuca	White-backed piping crow	3
Pica nuttalli	Yellow-billed magpie	3
Pica pica hudsonia	American magpie	6
Urocissa occipitalis	Red-billed blue magpie	2
Xanthoura luxuosa guatemalensis	Guatemalan green jay	1
Paradiseidae:		
Manucodia atra	Black manucode	1
Paradisea minor	Lesser bird of paradise	2
Paradisea rubra	Red bird of paradise	10
Schlegelia wilsoni	Wilson's bird of paradise	1
Seleucides niger	12-wired bird of paradise	3
Ptilonorhynchidae:		
Ptilonorhynchus violaceus	Satin bower bird	4
Timaliidae:		
Pomatorhinus erythrogenys imberbis	Salvadori's scimitar-babbler	1
Pycnonotidae:		
Molpastes haemorrhous	Black-headed bulbul	1
Otocompsa jocosus	Red-eared bulbul	1
Pycnonotus analis	Yellow-vented bulbul	2
Pycnonotus bindentatus	Orange-spotted bulbul	3
Rubigula dispar	Red-throated bulbul	3
Trachycomus zeylonicus	Yellow-crowned bulbul	4
Irenidae:		
Irena puella	Fairy blue bird	1
Turdidae:		
Mesia argentauris	Silver-eared mesia	2
Mimocichla rubripes	Western red-legged thrush	4
Turdus grayi	Bonaparte's thrush	1
Turdus migratorius	Robin	1
Laniidae:		
Lanius dorsalis	Teita fiscal shrike	2
Sturnidae:		
Aplonis chalybea	Glossy aplonis	2
Cosmopsaris regius	Splendid starling	3
Creatophora cinerea	Wattled starling	2
Galeopsar salvadorii	Crested starling	1
Gracula javana	Javan mynah	4
Gracula palawanensis	Palawan mynah	2
Gracula religiosa	Southern hill mynah	2
Gracupica melanoptera	Gray starling	4
Lamprocolius sycobius	Southern glossy starling	1

		Number
Coerebidae:		
Cyanerpes cyaneus	Blue honey creeper	1
Icteridae:		
Agelaius assimilis	Cuban red-winged blackbird	5
Agelaius icterocephalus	Yellow-headed marsh bird	1
Gymnomystax mexicanus	Giant oriole	2
Icterus giraudi	Giraud's oriole	1
Molothrus ater	Cowbird	1
Psomocolax oryxivora	Rice grackle	1
Xanthocephalus xanthocephalus	Yellow-headed blackbird	4
Thraupidae:		
Piranga erythromelas	Scarlet tanager	1
Spindalis pretrei	Cuban spindalis	1
Tanagra luteicapilla	Yellow-crowned euphonia	1
Thraupis cana	Blue tanager	2
Thraupis palmarum melanoptera	Palm tanager	1
Ploceiidae:		
Amadina fasciata	Cut-throat finch	1
Coliuspasser ardens	Red-necked whydah	3
Diatropura procne	Giant whydah	6
Munia maja	White-headed munia	30
Munia molucca	Black-throated munia	15
Munia oryzivora	White Java sparrow	2
	Java sparrow	12
Munia punctulatus	Rice bird	5
Ploceus baya	Baya weaver	5
Ploceus intermedius	Black-cheeked weaver	15
Ploceus rubiginosus	Chestnut-breasted weaver	8
Poephila acuticauda	Long-tailed finch	13
Poephila gouldiae	Gouldian finch	5
Quelea sanguinirostris intermedia	Southern masked weaver finch	1
Steganopleura bichenovii	Banded finch	6
Steganura paradisea	Paradise whydah	7
Taeniopygia castanotis	Zebra finch	2
Fringillidae:		
Amandava amandava	Strawberry finch	75
Carduelis carduelis	European gold finch	1
Erythrura prasina	Long-tailed munia	2
Fringilla montifringilla	Brambling finch	1
Melopyrrha nigra	Cuban bullfinch	1
Paroaria cucullata	Red-crested or Brazilian cardinal	2
Pheucticus tibialis	Yellow grosbeak	1
Serinus canarius	Canary	4
Sicalis minor	Lesser yellow finch	1
Sporophila aurita	Hick's seed-eater	4
Sporophila gutturalis	Yellow-bellied seed-eater	3
Tiaris canora	Melodius grassquit	3
Uroloncha sp	Society finch	2
Volatinia jacarini	Blue-black grassquit	1

Reptiles

LORICATA

		Number
Crocodylidae:		
Alligator mississipiensis	Alligator	36
Alligator sinensis	Chinese alligator	3
Caiman sclerops	Caiman	3
Crocodylus acutus	American crocodile	1
Crocodylus cataphractus	West African crocodile	1
Crocodylus porosus	Salt-water crocodile	1
Osteolaemus tetraspis	Broad-nosed crocodile	1
Tomistoma schlegeli	Malayan gavial	7

SQUAMATA

Lacertidae:		
Lacerta muralis	Wall lizard	1
Agamidae:		
Acanthosaura armata	Armed tree lizard	2
Physignathus cocincinus	Siamese water dragon	2
Physignathus lesueurii	Lesueur's water dragon	1
Iguanidae:		
Anolis carolinensis	False chameleon	12
Anolis equestris	Giant anolis	8
Anolis porcatus	Cuban anolis	2
Conolophus subcristatus	Galapagos iguana	1
Cyclura cornuta	Rhinoceros iguana	1
Iguana sp	Rock iguana	1
Leiocephalus cubensis	Cuban curl-tailed lizard	4
Phrynosoma cornutum	Horned lizard	6
Phrynosoma platyrhinos	Horned lizard	3
Sceloporus magister	Western spiny lizard	1
Sceloporus torquatus	Scaly lizard	4
Sceloporus undulatus	Fence lizard	3
Anguidae:		
Ophisaurus apus	European glass snake	1
Gerrhosauridae:		
Gerrhosaurus validus	Robust plated lizard	1
Helodermatidae:		
Heloderma horridum	Mexican beaded lizard	4
Heloderma suspectum	Gila monster	8
Teiidae:		
Cnemidophorus s. sexlineatus	Six-lined lizard	3
Tupinambis nigropunctatus	Tegu lizard	2
Scincidae:		
Egernia cunninghami	Cunningham's skink	3
Eumeces fasciatus	Red-headed skink	1
Eumeces obsoletus	Brown skink	3
Tiliqua nigrolutea	Mottled lizard	1
Tiliqua scincoides	Blue-tongued lizard	2
Trachysaurus rugosus	Stump-tailed lizard	1

		Number
Varanidae:		
Varanus gouldii	Gould's monitor	1
Varanus griseus	Gray monitor	1
Varanus komodoensis	Komodo dragon	1
Varanus niloticus	African monitor	1
Varanus salvator	Sumatran monitor	13

OPHIDIA

Boidae:		
Boa canina	Green tree boa	1
Boa cookii	Cook's tree boa	1
Constrictor constrictor	Common boa	1
Epicrates angulifer	Cuban tree boa	3
Epicrates cenchris	Rainbow boa	11
Epicrates striatus	Haitian boa	2
Eryx johni	Indian sand boa	1
Eunectes murinus	Anaconda	1
Tropidophis melanurus	Cuban boa	1
Pythonidae:		
Python amethystinus	Amethystine python	1
Python curtus	Blood python	3
Python molurus	Indian python	4
Python regius	Ball python	1
Python reticulatus	Regal python	5
Python sebae	African rock python	3
Python variegatus	Carpet python	2
Colubridae:		
Alsophis angulifer	Jubo or culebra	1
Boiga dendrophila	Mangrove snake	1
Coluber c. constrictor	Black snake	1
Drymarchon corais couperi	Indigo snake	12
Elaphe guttata	Corn snake	2
Elaphe obsoleta confinis	Southern pilot snake	1
Elaphe o. obsoleta	Pilot snake	5
Elaphe quadrivittata	Chicken snake	2
Elaphe vulpina	Fox snake	1
Lampropeltis getulus boylii	Boyle's king snake	3
Lampropeltis getulus floridana	Florida king snake	3
Lampropeltis g. getulus	King snake	3
Lampropeltis getulus holbrooki	Holbrook's king snake	2
Lampropeltis rhombomaculata	Mole snake	1
Liopeltis vernalis	Smooth green snake	2
Natrix cyclopion	Water snake	10
Natrix sp	Water snake	10
Pituophis catenifer	Western bull snake	1
Pituophis melanoleucus	Bull snake	2
Pituophis sayi	Pine snake	1
Storeria dekayi	DeKay's snake	3
Thamnophis sauritus	Ribbon snake	3
Thamnophis sirtalis concinnus	Pacific garter snake	15
Thamnophis s. sirtalis	Garter snake	2

		Number
Elapidae:		
Micrurus fulvius	Coral snake	1
Naja hannah	King cobra	2
Naja tripudians sumatrana	Sumatran black-hooded cobra	1
Naja tripudians (var.)	Spectacled cobra	3
Naja tripudians (var.)	Siamese black-hooded cobra	3
Notechis scutatus	Australian tiger snake	1
Crotalidae:		
Agkistrodon mokasen	Copperhead	2
Agkistrodon piscivorus	Water moccasin	6
Crotalus adamanteus	Diamond-backed rattlesnake	1
Crotalus cinerius	Desert rattlesnake	1
Crotalus horridus	Banded rattlesnake	4
Sistrurus catenatus catenatus	Massasauga	1
Sistrurus miliarius	Pigmy rattlesnake	1
Viperidae:		
Atheris chlorechis	West African tree viper	2
Bitis gabonica	Gaboon viper	1

TESTUDINATA

Chelydidae:		
Chelodina longicollis	Australian snake-necked turtle	3
Chelys fimbriata	Matamata turtle	1
Hydromedusa tectifera	South American snake-necked turtle.	6
Platemys platycephala	Flat-head turtle	1
Platysternidae:		
Platysternum megacephalum	Large-headed Chinese turtle	2
Pelomedusidae:		
Pelomedusa galeata	Common African water-tortoise	2
Podocnemis expansa	South American river tortoise	1
Kinosternidae:		
Kinosternon flavescens	Musk turtle	1
Kinosternon subrubrum	Musk turtle	4
Chelydridae:		
Chelydra osceola	Osceola snapping turtle	1
Chelydra rossignonii	Rossignon's snapping turtle	1
Chelydra serpentina	Snapping turtle	4
Macrochelys temminckii	Alligator snapping turtle	1
Testudinidae:		
Chrysemys picta	Painted turtle	2
Clemmys guttata	Spotted turtle	1
Clemmys muhlenbergii	Muhlenberg's tortoise	1
Cyclemys amboinensis	Malayan box turtle	18
Deirochelys reticularia	Chicken tortoise	1
Geoclemmys subtrijuga	Siamese field turtle	1
Geomyda spinosa	Spiny hill tortoise	1
Gopherus polyphemus	Gopher tortoise	1
Malaclemmys centrata	Diamond-back terrapin	8
Pseudemys concinna	Cooter	5
Pseudemys decussata	Haitian terrapin	1
Pseudemys elegans	Cumberland terrapin	2
Pseudemys floridana	Florida terrapin	2
Pseudemys rugosus	Cuban terrapin	2

		Number
Testudinidae—Continued.		
Terrapene carolina	Box tortoise	25
Terrapene major	Florida box turtle	2
Testudo elephantina	Aldabra tortoise	1
Testudo emys	Sumatran land tortoise	1
Testudo ephippium	Duncan Island tortoise	2
Testudo hoodensis	Hood Island tortoise	2
Testudo tabulata	South American tortoise	1
Testudo torneri	Soft-shelled land tortoise	4
Testudo vicina	Albemarle Island tortoise	1
Trionychidae:		
Amyda ferox	Soft-shelled turtle	8
Trionyx cartilagineus	Asiatic soft-shelled turtle	1

AMPHIBIA

CAUDATA

Salamandridae:		
Aneides lugubris	Salamander	1
Batrachoseps attenuatus	Salamander	1
Ensatina eschscholtzii	Salamander	1
Triturus pyrrhogaster	Red-bellied Japanese newt	6
Triturus viridescens	Common newt	18
Amphiumidae:		
Amphiuma means	Blind eel or Congo snake	2
Amphiuma tridactylum	Blind eel or Congo snake	1
Megalobatrachus japonicus	Giant salamander	1
Cryptobranchidae:		
Cryptobranchus alleganiensis	Hellbender	8

SALIENTIA

Brachycephalidae:		
Atelopus varius varius	Yellow atelopus	2
Discoglossidae:		
Bombina bombina	Fire-bellied toad	1
Dendrobatidae:		
Dendrobates auratus	Arrow-poison frog	30
Bufonidae:		
Bufo alvarius	Green toad	1
Bufo americanus	Common American toad	2
Bufo empusus	Sapo de concha	15
Bufo marinus	Marine toad	3
Bufo peltocephalus	Cuban giant toad	9
Bufo superciliosus	Leaf toad	1
Ceratophrydae:		
Ceratophrys varius	Horned toad	2
Hylidae:		
Hyla caerulea	Australian tree frog	7
Hyla cinerea	Florida tree frog	1
Hyla crucifer	Tree frog	4
Hyla septentrionalis	Cuban tree frog	5
Pipidae:		
Pipa americana	Surinam toad	1
Xenopus sp	Smooth-clawed frog	3

		Number
Ranidae:		
Rana catesbeiana	Bull frog	1
Rana clamitans	Green frog	1
Rana sphenocephala	Southern leopard frog	1

FISHES

Acanthopthalmus kuhlii	Banded loach	6
Anguilla rostrata	Common eel	3
Barbus sp		1
Brachydanion rerio	Zebra fish	2
Corydoras aeneus	Trinidad armored catfish	4
Corydoras melanistius	Armored catfish	1
Electrophorus electricus	Electric eel	1
Helostoma temminckii	Kissing gourami	1
Hemigrammus unilineatus		1
Hypostomus sp	Armored catfish	1
Kryptopterus bicirrhus	Glass catfish	5
Lebistes reticulatus	Guppy	50
Lepidosiren paradoxa	South American lungfish	3
Monocirrhus polyacanthus	Leaf fish	3
Platypoecilus maculatus	Goldplaties	20
Pristella riddlei		5
Protopterus annectens	African lungfish	2
Pterophyllum scalare	Angel fish	1
Rasbora heteromorpha		3
Trichogaster trichopterus	Three-spot gourami	3
Xiphophorus hellerii	Swordtail	1

ARACHNIDS

Eurypelma sp	Tarantula	3
Latrodectus mactans	Black widow spider	4

INSECTS

Blabera sp	Giant cockroach	100

MOLLUSKS

Achatina variegata	Giant land snail	6

Respectfully submitted.

W. M. MANN, *Director.*

Dr. C. G. ABBOT,
Secretary, Smithsonian Institution.

APPENDIX 8

REPORT ON THE ASTROPHYSICAL OBSERVATORY

Sir: I have the honor to submit the following report on the activities of the Astrophysical Observatory for the fiscal year ended June 30, 1938:

WORK AT WASHINGTON

RECOMPUTATIONS

The recomputation of solar-constant values under the direction of L. B. Aldrich, referred to in last year's report, was the main business. A considerable force of extra computers was employed on a job basis under grants-in-aid from John A. Roebling. Also a considerable force of W. P. A. workers was assigned to the project. With the regular force and these extra workers the immense task is nearly completed. It is hoped to finish the entire recomputations and comparisons of solar-constant results from all stations by January 1939, so as to make up a homogeneous series of daily values from 1923 to the present time.

STELLAR SPECTRUM ENERGY CURVES

In 1922, 1923, 1928, and 1934, attempts were made, in cooperation with the Mount Wilson Observatory, to measure the distribution of energy in the spectra of some of the brighter stars. The measurements were made in the focus of the 100-inch reflecting telescope. Results of some value were reached in 1923 and 1928, using a prismatic spectroscope and the radiometer. In 1934 it was attempted, in cooperation with Dr. Joel Stebbins, to observe at 10 wave lengths selected by Christiansen filters, employing a photoelectric cell. Unfortunately, owing to the great inequality of sensitiveness of the cell for different wave lengths of radiation, these observations proved valueless.

Since 1934 repeated attempts have been made at Washington to devise a radiation-measuring instrument with a black absorbing surface. We desired to attain sufficient sensitiveness to get good measurements with the Christiansen filters for stars as faint as third magnitude. In the opinion of able astronomers this would be a highly valuable accomplishment, indeed one of the most interesting

114728—39——8

for astronomy. It is to be hoped that when the 200-inch telescope becomes available such a sensitive measuring instrument may be used successfully with a prismatic or grating spectroscope, and with photographic registration, so as actually to secure continuous spectral energy curves of the brighter stars.

In our attempts to realize the highly sensitive measuring device, we tried for several months to perfect the kampometer, but it did not quite reach our demands. We then turned to the improvement of the galvanometer, hoping to use it to observe the indications of the delicate thermopile such as L. B. Clark now constructs for use in the Division of Radiation and Organisms. Our intention was to employ with the galvanometer the magnetic shield which was constructed for us about 18 years ago by the late Dr. Elihu Thomson of Lynn, and to insert therein, in highly evacuated space, a galvanometer of the Kelvin suspended magnetic system type. We hoped by high evacuation to be able to use a very light system at a time of single swing as high as 10 seconds, and that the sensitiveness would be found nearly proportional to the square of time of swing, even up to this long period. As the magnetic shield is very effective indeed, we attempted at first to use a galvanometer of only one pair of coils, with a single group of magnets. But while this arrangement is evidently the most sensitive possible, we found that what was gained in sensitiveness was more than lost in instability. Accordingly, we constructed an astatic system with two opposed groups of magnets separated but little over 10 millimeters between centers, and two pairs of correspondingly small coils, making a combined resistance of about 17 ohms.

Preliminary trials at Washington indicated a high sensitiveness, but with the mechanical and electrical disturbances unavoidable in a city, we could not tell whether the stability was adequate. To test this question, Messrs. Abbot and Hoover observed, by invitation, with this galvanometer at John A. Roebling's estate in Florida in March 1938. They found a 10-second single swing easily practicable; the proportionality of sensitiveness to the square of time of swing nearly followed up to that period, and the stability was so good that readings at a scale distance of 5 meters seemed likely to disclose vibrations only rarely exceeding 1 millimeter in amplitude.

Tests with the thermopile and candle flame seemed to indicate that the new combination would prove between 10 and 100 times as effective as the combination employed by Dr. Abbot in 1928. Mr. Hoover made a new and better magnetic system after returning from Florida. The excellent showing of the galvanometer is almost wholly due to his work, though based on the extensive researches of Messrs. Abbot and Fowle about the years 1898 to 1900.

In May 1938 Mr. Hoover went to Mount Wilson to prepare for new measurements of the energy in the spectra of the stars, and to make studies of the growth of plants in monochromatic rays, taken from sunlight by Christiansen filters. It may be said, by anticipation, that in both researches Mr. Hoover has been able to make gratifying progress, as will be reported next year. It may even be said now with confidence that when the 200-inch telescope is available it will be possible to get excellent continuous stellar spectrum energy curves for all types of stars. Thus far Mr. Hoover has succeeded in measuring electric currents with his 17-ohm galvanometer of 1×10^{-12} amperes, and to observe the rays of a candle flame on a thermoelement of 1 millimeter diameter from a candle distance of 150 meters.

ATMOSPHERIC TURBIDITY AND MOISTURE APPARATUS

In 1930 we constructed a special instrument, containing a spectrobolometer, an Ångström pyrheliometer, and a pyranometer, for the use of Mr. Moore in testing the availability of mountain sites in and near Africa for solar-constant work. With this portable instrument he could determine the total precipitable water in the atmospheric path of sun rays, as well as total intensity of solar radiation, and the brightness of the sky. This instrument came to the attention of the United States Weather Bureau, and was considered to be of much promise for their work. At the request of Chief Gregg, the Smithsonian Institution has undertaken to duplicate it for the Weather Bureau, and the instrument maker, Mr. Kramer, is at work thereon.

UTILIZING SOLAR RADIATION

Some further progress has been made by Dr. Abbot on devices for utilizing solar radiation. While in Florida, in March, he tried out with gratifying results a solar flash boiler, a solar water distiller, and a toy solar cooker.

FIELD STATIONS

Several considerations led to the abandonment of the Mount St. Katherine solar-radiation station in December 1937. The isolation of the station made its occupation hazardous. Its remoteness and isolation made its upkeep costly. An intestinal infection attacked all of the observers and proved stubborn to cure. The likelihood of a great European war made it probable that the observatory might be wholly cut off from Washington. The station was abandoned with regret, for meteorologically it had proved to be excellent, perhaps equal to Montezuma.

Instead of St. Katherine, it was decided to locate a station in southwestern New Mexico. This location seemed to partake of the climatological advantages of Old Mexico. Our other stations, both northern and southern, have all had relatively bad observing conditions in the months December to March. In Old Mexico and southwestern New Mexico, on the contrary, these months promise to be the most cloudless of all.

A. F. Moore has located the new station on Burro Mountain near Tyrone, N. Mex., at a level of about 8,000 feet. The living conditions there seem to give promise of being quite as attractive as at Table Mountain. It lies not far from four fair-sized towns, the people of the vicinity are helpful and pleasant, and the United States Forest Service is exceedingly helpful and welcoming regarding the project. It is hoped to be ready to observe in October or November 1938.

With two pleasant stations besides Washington in the United States, and one more isolated one in Chile, it seems feasible to rotate the observers hereafter without undue privation.

The stations at Table Mountain and Montezuma have continued to observe the solar constant of radiation daily, when possible.

ULTRAVIOLET SOLAR RADIATION

Having failed thus far to obtain sufficient financial support to operate enough solar-constant stations to determine adequately the variation of the sun on every day of the year, as referred to in last year's report, it has been hoped to accomplish in some other way a program of measuring solar variation as influencing weather. Several possibilities exist. For recent years, in America, England, and Australia, records of atmospheric ionization at great altitudes are being obtained by several institutions and individuals. The ionization is thought to be dependent on solar radiation, far in the ultraviolet spectrum, at wave lengths less than 1000 angstroms. Results seem to indicate that these rays vary over a great range, perhaps as much as 500 percent. It is hoped that these measurements may be correlated with weather.

Inasmuch, however, as both theory and our preliminary observations indicate that the variation of the sun, which is only of the order of 1 or 2 percent in the total radiation, may be as great as 15 or 20 percent at ultraviolet wave lengths about 3300 angstroms, it was hoped that automatic sounding balloon methods might be developed whereby the variation of the sun's radiation in this part of the ultraviolet spectrum could be measured accurately enough for weather predicting. To this end the Smithsonian Institution made two grants in aid to Dr. Brian O'Brien, of Rochester, N. Y. Dr. O'Brien, aided also by the University of Rochester and by several

generous manufacturing corporations, has gone far to develop highly ingenious methods and apparatus for measuring solar variation in the ultraviolet from sounding balloons, automatically observed on the ground through radio transmission of signals. He hopes soon to be in position to compare this type of results with those of solar-constant work reported from our stations.

PUBLICATION

Dr. Abbot published a résumé of his studies on solar variation and weather changes in a number of the Czechoslovak scientific journal concerning physics, prepared in honor of Dr. S. Hanzlik. A small number of separates of this résumé are available for distribution if solicited by interested parties.

PERSONNEL

F. E. Fowle, who entered the service of the Astrophysical Observatory in 1894, having been retired for disability, W. H. Hoover, who has heretofore had special status with the Astrophysical Observatory, as a field director, was promoted to the position of Senior Astrophysicist on October 16, 1937.

Respectfully submitted.

C. G. Abbot, *Director.*

The Secretary,
Smithsonian Institution.

APPENDIX 9

REPORT ON THE DIVISION OF RADIATION AND ORGANISMS

SIR: I have the honor to submit the following report on the activities of the Division of Radiation and Organisms during the year ended June 30, 1938:

The fundamental facts relating to plant growth and radiation have been fruitfully pursued by the Division during the year. Mr. Hoover, temporarily loaned for studies of radiation and photosynthesis, had been recalled for continuous work with the Astrophysical Observatory. To assist in these and other plant studies under Dr. Johnston's immediate direction, Dr. R. L. Weintraub was engaged. He developed an improved method of measuring plant growth substances which are concerned in the bending of plants toward the light. A description of this method with data from a number of experiments is now ready for publication under the title, "An assay method for plant growth substances utilizing straight growth of the *Avena* coleoptile." Dr. Weintraub is continuing the earlier work of Dr. Johnston on the growth of the first internode in light of very low intensities and in different spectral regions. It is interesting to note that the plant responds to light intensities far below those which can be detected by the most sensitive thermocouples.

Messrs. Johnston, McAlister, Weintraub, Clark, and Fillmen have been preparing a new automatic apparatus for measuring and recording photosynthesis continuously. It is similar in nature to the device employed by Dr. McAlister, to which reference was made in last year's report, but with the added feature of continuous automatic photographic registration. This new apparatus was nearly ready for use at the close of the fiscal year. It is to be used with a powerful light source, comprising a 60-inch army searchlight, loaned by the War Department, and a battery of mirrors at the focus of the beam so placed that slender plants such as wheat, or others, may be illuminated strongly from all sides. Experiments of many kinds relating to photosynthesis and the formation of chlorophyll are about to be taken up with this efficient outfit. Another piece of apparatus has been developed for the determination of chlorophyll. Very good results can be obtained with concentrations as low as 0.1 mg chlorophyll per liter of solution. This equipment is being used in con-

nection with the CO_2 absorption studies and the formation of chlorophyll.

Among other projects, photosynthesis in algae is to be investigated. In preparation for this research Dr. Johnston and Dr. Meier have been testing various methods of producing thin coatings of living algae on rods and plates, without the interposition of water layers between the algae and such light source as may be employed. Successful cultures of this sort have been made.

Dr. Meier had a very serious fall in early December 1937 and was incapacitated until June 1938, but returned to work part time in June and full time in July. Prior to her accident she made further observations on stimulation of multiplication of algae by ultraviolet rays which in larger dosage would be lethal. While the results obtained certainly point strongly to a positive conclusion, further work must be done before publication.

Dr. Johnston has continued investigations on mixtures of artificial lights suitable to promote fully satisfactory plant growth under laboratory conditions.

Dr. McAlister has made prolonged further studies on the dependence of the induction periods in the photosynthesis of wheat on the length of previous dark exposures. In addition, an uptake of CO_2 by leaves in darkness has been discovered which has an important bearing on photosynthesis. These phenomena are held by students of photosynthesis to be of the greatest possible interest in obtaining an understanding of the fundamental reactions which occur in plants under the influence of light. Until the perfection of the technique by Dr. McAlister, and his introduction of spectroscopy, as a highly sensitive means of instantaneously measuring carbon dioxide assimilation, the subject was practically beyond the possibility of investigation. But during the past year he has accumulated great numbers of results which are the foundation of a paper he will shortly publish under the title: "Chlorophyll—CO_2 ratio during photosynthesis," which it is believed will be of the very highest interest to students of this subject. As heretofore the technical work of the Division has been ably promoted by Messrs. Clark and Fillmen.

As noted under the Report on the Astrophysical Observatory, Mr. Hoover has made interesting experiments at Mount Wilson, Calif., on growing plants to maturity in narrow ranges of spectrum selected from the sunbeam. This work will be described in next year's report.

The following publications have been issued from the Division during the fiscal year:

Johnston, Earl S.

Phototropic response and CO_2 assimilation of plants in polarized light. Smithsonian Misc. Coll., vol. 96, No. 3. 1937.

Growth of *Avena* coleoptile and first internode in different wave-length bands of the visible spectrum. Smithsonian Misc. Coll., vol. 96, No. 6, 1937.

Plant growth in relation to wave-length balance. Smithsonian Misc. Coll., vol. 97, No. 2, 1938.

Sun rays and plant life. Smithsonian Ann. Rep. 1936, pp. 353–371, 1937.

Meier, Florence E.

Reactions to ultraviolet radiation. Smithsonian Ann. Rep. 1936, pp. 373–382, 1937.

Respectfully submitted.

C. G. Abbot, *Director*.

The Secretary,
Smithsonian Institution.

APPENDIX 10

REPORT ON THE LIBRARY

Sir: I have the honor to submit the following report on the activities of the Smithsonian library for the fiscal year ended June 30, 1938:

THE LIBRARY

The library, or library system, of the Smithsonian comprises 45 libraries. Chief among these are the Smithsonian deposit in the Library of Congress, which is the main library of the Institution, and the libraries of the United States National Museum and the Bureau of American Ethnology. The others are the Langley aeronautical library, also deposited in the Library of Congress, the Smithsonian office library, the libraries of the Astrophysical Observatory, Freer Gallery of Art, National Collection of Fine Arts, National Zoological Park, Radiation and Organisms, and the sectional libraries, 35 in number, of the National Museum.

PERSONNEL

Two changes occurred in the library staff. Mrs. George C. Rodgers, senior stenographer, withdrew from Government service, and the position was reclassified to that of assistant clerk-stenographer and filled by the appointment of Miss Nancy Alice Link, through transfer from the Bureau of Internal Revenue. The assistant messenger, Joseph A. Salat, Jr., resigned and Clyde E. Bauman was transferred to the vacancy from the United States Naval Academy. The temporary assistants were Mrs. Gladys S. Wilson, Miss Margaret Kober, and 17 employees assigned to the library by the Works Progress Administration.

EXCHANGE OF PUBLICATIONS

The exchange work of the library was noteworthy. It brought to the receiving room 22,800 packages by mail and 2,464 by the International Exchange Service—a total of 25,264, each containing one or more publications. Besides several generous sendings from the United States, such as those from the American Antiquarian Society, the Paleontological Institution, and the University of Washington, there were many from abroad, the largest being from the Koninklijke

Akademie van Wetenschappen, Amsterdam; Učená Společnost Šafaříkova, Bratislava; Academie Royale des Sciences de Belgique, Brussels; Polskiego Towarzystwa Przyrodników im. Kopernika, Lwów; Royal Society of Victoria, Melbourne; Naturforscher-Verein zu Riga, Riga; Kgl. Norske Videnskabernes Selskab, Trondheim; and the universities of Basel, Cambridge, and Lille.

The 6,037 dissertations received represented an increase of 670 over the year before. Of these, 2,265 were added to the Smithsonian deposit, 2,971, having to do largely with medical subjects, were turned over to the Surgeon General's library, and the rest, being duplicates, were sent, under a special exchange arrangement, to Columbia University. They came from the universities of Basel, Berlin, Bern, Bonn, Breslau, Cornell, Erlangen, Freiburg, Giessen, Greifswald, Heidelberg, Jena, Kiel, Königsberg, Louvain, Lund, Lwów, Marburg, Neuchâtel, Pennsylvania, Rostock, Strasbourg, Tübingen, Utrecht, Würzburg, and Zürich, and the technical schools of Berlin, Braunschweig, Delft, Dresden, Karlsruhe, and Zürich.

The number of letters—2,403—prepared by the staff in course of the exchange and other work of the library was larger than in 1937, as was the number of publications obtained by special request to meet needs in the various libraries of the Institution. The latter totaled 5,315, more than one-half of which were for the library of the National Museum. In connection with the effort to provide by exchange publications essential to the work of the Smithsonian and its bureaus, the library staff handled 582 want cards and arranged for 285 new exchanges. It should be said, however, in passing, that hundreds of the volumes and parts in question were found among the duplicates in the west stacks, a further indication of the value of this collection and of the effectiveness of the organization to which it has been subjected.

Finally, it is a pleasure to report that the year marked the return to stock of numerous sendings, both large and small, of Smithsonian publications from libraries outside of Washington where they were duplicates. Thus the supply available for exchange use was again substantially increased.

GIFTS

The gifts during the year were numerous. From the Geophysical Laboratory came 3,312 miscellaneous publications, from the American Association for the Advancement of Science 653, and from the American Association of Museums 209, among them a goodly number of scientific serials that were especially welcome.

From the libraries of the late Dr. Walter Hough and Dr. Frederick V. Coville, former members of the scientific staff, came, through Mrs. Hough and Mrs. Coville, many important books and pamphlets.

And from Mrs. Charles D. Walcott and the scientists of the Institution, notably Secretary Abbot and Assistant Secretary Wetmore, even more publications than usual were received.

But perhaps the outstanding gift of the year was made by Mrs. William Woodville Rockhill, widow of the one-time American Minister to China. This consisted of 1,186 volumes and pamphlets, chiefly in Chinese and other Eastern languages, on the history and culture of China. It was assigned, naturally, to the library of the Freer Gallery of Art, where it supplements in a notable way the Rockhill and other collections, as these supplement appreciably, for research purposes, the Division of Orientalia in the Library of Congress.

Other gifts included the following: La Mostra del Tintoretto, Catalogo delle Opere, from Count Urbano de Bellegarde; Pintura Mexicana (1800–1860), by Roberto Montenegro, from Angel Rosas; Turkey in Pictures, from his Excellency, the Turkish Ambassador to the United States; Description Géométrique Détaillée des Alpes Françaises, Annexe du Tome Second and Annexe du Tome Dixième (2 copies of each), by Paul Helbronner, from Le Maréchal Pétain; reprint of The Cactaceae, in 4 volumes, by N. L. Britton and J. N. Rose (Publication No. 248 of the Carnegie Institution of Washington), from The Cactus and Succulent Society of America; Nikola Tesla, a volume issued on the occasion of his 80th birthday, from La Société pour la Fondation de l'Institut Nikola Tesla; A Catalogue of the Pictures and Drawings in the Collection of Frederick John Nettlefold, Volumes III–IV, by C. Reginald Grundy and F. Gordon Roe, from Frederick John Nettlefold; Mollusques Terrestres et Fluviatiles d'Asie-Mineure (Voyage Zoologique d'Henri Gadeau de Kerville en Aise-Mineure), by Louis Germain, from Henri Gadeau de Kerville; The Works of Edwin Howland Blashfield, with an Introduction by Royal Cortissoz, from Mrs. Grace Hall Blashfield; The Geology of Pennsylvania, Volume I and Volume II, Parts 1 and 2, by Henry Darwin Rogers, from John W. Berry for the family of the late R. D. Lacoe, who, before his death in 1900, presented the Institution with a valuable collection of coal fossils and his library on paleozoölogy; The Birds of Tropical West Africa, Volume IV, by David Armitage Bannerman, from The Crown Agents for the Colonies, London; Captains and Mariners of Early Maryland, by Dr. Raphael Semmes, from the author; Complete Self-Instructing Library of Practical Photography, in 10 volumes, edited by S. B. Schriever, from Mrs. A. B. Stebbins; Automobilens Historia, by John Nerén, from the author; 15 books and pamphlets on various subjects, including Historia de la Medicina en el Uruguay, Volumes 1–2, by Rafael Schiaffino, and Historia de la Dominación Española en el Uruguay, Volumes 1–3, by Francisco Bauza, from Dr. Rafael Schiaf-

fino; Art and Archaeology Abroad, by Dr. Kalidas Nag, from the author; Old New York from the Battery to Bloomingdale, etchings by Eliza Greatorex, text by M. Despard, from Mrs. Walter S. Pratt, Jr.; Interpretive History of Flight, by M. J. B. Davy, from the author; The Americana Annual for 1937 and 1938, from the editor; The Great Chain at West Point and Other Obstructions Placed in the Hudson River during the War of the Revolution, by B. F. Fackenthal, Jr., from the author; The Phonetics of the Hottentot Language, by D. M. Beach, from the Research Grant Board, Johannesburg; Hints on Museum Education, by J. C. Basak, from the author; and The Tracy Genealogy, by Sherman Weld Tracy, from the author.

SOME STATISTICS

Accessions to the libraries:

	Volumes	Pamphlets and charts	Total	Approximate holdings, June 30, 1938
Astrophysical Observatory	162	132	294	9,491
Bureau of American Ethnology	395		395	51,395
Freer Gallery of Art	634	69	703	13,377
Langley Aeronautical	45	21	66	3,394
National Collection of Fine Arts	285	271	556	6,340
National Museum	2,639	929	3,568	210,710
National Zoological Park	149	21	170	3,741
Radiation and Organisms	17	7	24	269
Smithsonian deposit, Library of Congress	3,018	1,974	4,992	558,070
Smithsonian office	106	18	124	30,627
Total	7,450	3,442	10,892	[1] 887,414

[1] These holdings do not, of course, include the thousands of volumes still incomplete, uncataloged, or unbound.

The staff recorded 23,992 periodicals; cataloged 6,449 publications; prepared and filed 42,568 catalog and shelf list cards; borrowed 2,239 volumes from the Library of Congress and other libraries; and made 11,380 loans, 340 of which were to libraries outside the Smithsonian system. They also advanced materially the index of exchange relations and the index of Smithsonian publications. The work on the union catalog was as follows:

Volumes cataloged	3,439
Pamphlets and charts cataloged	2,307
New serial entries made	165
Typed cards added to catalog and shelf list	5,979
Library of Congress cards added to catalog and shelf list	13,890

OTHER ACTIVITIES

The staff took down the exhibition set of Smithsonian publications that for 10 years had formed an imposing monument in the main hall and filed it away for future service. They brought together the archives set, checked it, and shelved it in a safe and convenient place.

They supervised the 17 W. P. A. employees assigned to the library in such tasks as cleaning, repairing, and binding books, putting pamphlets into binders and lettering them, renovating plates and maps, typing cards, filling out acknowledgment forms, mounting aeronautical clippings, sorting and filing duplicates, and assisting with the cataloging.

They effected special exchanges of duplicates with the libraries of the Massachusetts Institute of Technology, Marine Biological Laboratory, Woods Hole, Staten Island Association of Arts and Sciences, American Museum of Natural History, United States Patent Office, and the following colleges and universities: Brown, California, Catholic, Columbia, Duke, Harvard, Michigan, North Carolina, Pennsylvania, Princeton, Stanford, Williams, and Yale. By these transactions they placed many publications not wanted by the Institution where they would be useful and obtained many that were needed in the collections. Among the latter were Forges and Furnaces in the Province of Pennsylvania, issued by the Pennsylvania Society of the Colonial Dames of America; The Cannon Collection of Italian Paintings of the Renaissance, mostly of the Veronese School, by J. Paul Richter; The African Republic of Liberia and the Belgian Congo, Volume II, edited by Richard P. Strong; A Guide to the History and Historic Sites of Connecticut, in 2 volumes, by Florence S. M. Crofut; Practice of Tempera Painting, and Materials of Medieval Painting, by Daniel V. Thompson; Eclipses of the Sun, third edition revised and enlarged, by S. A. Mitchell; A Catalogue of the Epstean Collection on the History and Science of Photography and Its Applications Especially to the Graphic Arts, by Edward Epstean; Benjamin Franklin's Own Story, by Nathan G. Goodman; Roman Glass from Karanis, by Donald B. Harden; Annual Review of Biochemistry, Volume VII, edited by J. M. Luck and C. R. Noller; and numerous volumes and parts of the Meddelelser om Grønland.

The staff continued the revision of the files of society and engineering publications in the natural history and technological libraries of the National Museum, thus making these important sets more available for use. The work with the latter was expedited by the arrival of the steel shelving that had been ordered toward the close of 1937.

They finished recataloging the sectional library of botany and began that of administration.

And they spent even more time than usual identifying for the scientists of the Institution obscure citations found in the literature of their respective subjects, and providing data, including not a few bibliographies, for letters in answer to requests for information received from different parts of the country.

BINDING

The allotment for binding was again very inadequate, permitting the libraries to bind only as follows: National Museum, 494 volumes; National Collection of Fine Arts, 45; Astrophysical Observatory, 36. The total, 575 volumes, was but a fraction of the number that, for the good of the collections, should have been bound. It is earnestly hoped that more funds can soon be made available for binding, that this interest of the Smithsonian libraries—an interest essential to their preservation and usefulness—may be provided for satisfactorily. In 1935 the average charge for binding was about $3.25 a volume, while in 1938 it had risen to approximately $5. This difference of $1.75 has woefully reduced the number of volumes that can be bound with the sums annually allowed for this purpose.

Fortunately, the Freer Gallery of Art, with funds of its own for binding, was able to have 57 volumes bound. Fortunately, too, the Smithsonian Institution, taking advantage of the services of an expert binder and of two assistants assigned to it under the W. P. A., was able to have 414 volumes bound and 148 volumes and 994 pamphlets repaired for several of its libraries.

But there remain thousands of unbound volumes, especially in the National Museum, Bureau of American Ethnology, Astrophysical Observatory, and National Collection of Fine Arts. Most of the volumes are made up of serial parts. As many of these are in daily use, they are constantly running the risk of being damaged or destroyed. And it frequently happens that a part, once lost, cannot be replaced, particularly if it belongs to a foreign volume of limited issue.

NEEDS

The need of increased funds for binding has already been mentioned. Other needs are only a little less urgent. They are as follows: Two or more well-trained catalogers to work chiefly in the main library in the Natural History Building; another messenger to assist in the libraries in the Smithsonian Building and the Arts and Industries Building; more shelf room for the library collections in all three of the principal buildings of the Institution.

Respectfully submitted.

William L. Corbin, *Librarian.*

Dr. C. G. Abbot,
Secretary, Smithsonian Institution.

APPENDIX 11

REPORT ON PUBLICATIONS

Sir: I have the honor to submit the following report on the publications of the Smithsonian Institution and the Government branches under its administrative charge during the year ended June 30, 1938:

The Institution published during the year 12 papers in the series of Smithsonian Miscellaneous Collections, 1 annual report, and pamphlet copies of the 23 articles in the report appendix, and 2 special publications.

The United States National Museum issued 1 annual report, 4 bulletins, 1 separate from Bulletin 100, 1 volume of the Proceedings, and 19 separates from Proceedings, volumes 84 and 85.

The Bureau of American Ethnology issued one annual report and three bulletins.

Of the publications there were distributed 129,478 copies, which included 87 volumes and separates of the Smithsonian Contributions to Knowledge, 27,223 volumes and separates of the Smithsonian Miscellaneous Collections, 22,593 volumes and separates of the Smithsonian Annual Reports, 4,200 Smithsonian special publications, 57,761 volumes and separates of the National Museum publications, 16,569 publications of the Bureau of American Ethnology, 67 publications of the National Collection of Fine Arts, 8 publications of the Freer Gallery of Art, 20 annals of the Astrophysical Observatory, 68 reports of the Harriman Alaska Expedition, and 882 reports of the American Historical Association.

SMITHSONIAN MISCELLANEOUS COLLECTIONS

Of the Smithsonian Miscellaneous Collections, volume 91, there were issued 3 papers; volume 96, 5 papers and title page and table of contents; and volume 97, 4 papers, making 12 papers in all, as follows:

VOLUME 91

Reports on the collections obtained by the first Johnson-Smithsonian Deep-Sea Expedition to the Puerto Rican Deep.

No. 27. A new species of deep-sea fish, *Argyropelecus antrorsospinus*, of the family Sternoptichidae, by Leonard P. Schultz. 5 pp., 1 fig. (Publ. 3439.) July 7, 1937.

114728—39——9

No. 28. New species of hydroids from the Puerto Rican region, by G. McLean Fraser. 7 pp., 2 pls. (Publ. 3443.) November 10, 1937.

No. 29. A new genus of starfishes from Puerto Rico, by Austin H. Clark. 7 pp., 1 pl. (Publ. 3481.) June 18, 1938.

VOLUME 96

No. 1. Archeology of St. Lawrence Island, Alaska, by Henry B. Collins, Jr. 431 pp., 84 pls., 26 figs. (Publ. 3411.) August 9, 1937.

No. 3. Phototropic response and CO_2 assimilation of plants in polarized light, by Earl S. Johnston. 7 pp., 1 fig. (Publ. 3440.) July 12, 1937.

No. 4. Indian sites below the falls of the Rappahannock, Virginia, by David I. Bushnell, Jr. 65 pp., 21 pls., 11 figs. (Publ. 3441.) September 15, 1937.

No. 5. The male genitalia of orthopteroid insects, by R. E. Snodgrass. 107 pp., 42 figs. (Publ. 3442.) September 25, 1937.

No. 6. Growth of Avena coleoptile and first internode in different wave-length bands of the visible spectrum, by Earl S. Johnston. 19 pp., 4 figs. (Publ. 3444.) November 6, 1937.

Title page and table of contents. (Publ. 3450.)

VOLUME 97

No. 1. Preliminary report on the Smithsonian Institution-Harvard University archeological expedition to northwestern Honduras, 1936, by William Duncan Strong, Alfred Kidder II, and A. J. Drexel Paul, Jr. 129 pp., 16 pls., 32 figs. (Publ. 3445.) January 17, 1938.

No. 2. Plant growth in relation to wave-length balance, by Earl S. Johnston. 18 pp., 4 pls. (Publ. 3446.) January 12, 1938.

No. 3. Middle Cambrian fossils from Pend Oreille Lake, Idaho, by Charles Elmer Resser. 12 pp., 1 pl. (Publ. 3447.) January 3, 1938.

No. 4. The feeding mechanism of adult Lepidoptera, by John B. Schmitt. 28 pp., 12 figs. (Publ. 3448.) January 10, 1938.

SMITHSONIAN ANNUAL REPORTS

Report for 1936.—The complete volume of the Annual Report of the Board of Regents for 1936 was received from the Public Printer in October 1937.

Annual Report of the Board of Regents of the Smithsonian Institution showing operations, expenditures, and condition of the Institution for the year ending June 30, 1936. xiv+446 pp., 122 pls., 26 text figs. (Publ. 3405.)

The appendix contained the following papers:

Astronomy in Shakespeare's time and in ours, by C. G. Abbot.
The size and age of the universe, by Sir James Jeans.
The earth, the sun, and sunspots, by Loring B. Andrews.
Northern lights, by A. S. Eve.
Radioactivity and atomic theory, by Lord Rutherford.
The cryogenic laboratory at Leiden, by Robert Guillien.
Form, drift, and rhythm of the continents, by W. W. Watts.
Core samples of the ocean bottom, by Charles Snowden Piggot.
Some new aspects of evolution, by W. P. Pycraft.
What is the meaning of predation? by Paul L. Errington.

The gorillas of the Kayonsa region, Western Kigezi, SW. Uganda, by Capt. C. R. S. Pitman.
The vampire bat: A presentation of undescribed habits and review of its history, by Raymond L. Ditmars and Arthur M. Greenhall.
Some of the commoner birds of Ceylon, by Casey A. Wood.
The wax palms, by Miriam L. Bomhard.
Significance of shell structure in diatoms, by Paul S. Conger.
Some aspects of the plant virus problem, by Kenneth M. Smith.
Sun rays and plant life, by Earl S. Johnston.
Reactions to ultraviolet radiation, by Florence E. Meier.
Aerial photography, by Capt. H. K. Baisley.
Easter Island, Polynesia, by Henri Lavachery.
The Eskimo archeology of Greenland, by Therkel Mathiassen.
Petroglyphs of the United States, by Julian H. Steward.
The history of the crossbow, illustrated from specimens in the United States National Museum, by C. Martin Wilbur.

Report for 1937.—The report of the Secretary, which included the financial report of the executive committee of the Board of Regents, and will form part of the annual report of the Board of Regents to Congress, was issued in January 1938.

Report of the Secretary of the Smithsonian Institution and financial report of the executive committee of the Board of Regents for the year ended June 30, 1937. 123 pp., 7 pls., 1 fig. (Publ. 3449.)

The report volume, containing the general appendix, was in press at the close of the year.

SPECIAL PUBLICATIONS

Explorations and field work of the Smithsonian Institution in 1937. 122 pp., 123 figs. (Publ. 3480.) April 9, 1938.

Radio Program Folders, "The World is Yours." Edition of 200,000 distributed by the Office of Education, United States Department of the Interior.

PUBLICATIONS OF THE UNITED STATES NATIONAL MUSEUM

The editorial work of the National Museum has continued during the year under the immediate direction of the editor, Paul H. Oehser. There were issued 1 annual report, 4 bulletins, and 1 separate from Bulletin 100, 1 volume of the Proceedings, and 19 separates from Proceedings volumes 84 and 85, as follows:

MUSEUM REPORT

Report on the progress and condition of the United States National Museum for the year ended June 30, 1937. iii+130 pp. January 1938.

PROCEEDINGS: VOLUME 84

Complete volume:

Proceedings of the United States National Museum. Vol. 84, viii+606 pp., 80 pls., 34 figs.

Separates:

No. 3017. Revision of the North American species of ichneumon-flies of the genus *Exetastes* Gravenhorst. By R. A. Cushman. Pp. 243–312, pls. 16–21. July 3, 1937.

No. 3019. Moths of the genus *Rupela* (Pyralididae: Schoenobiinae). By Carl Heinrich. Pp. 355–388, pls. 22–33. July 3, 1937.

No. 3021. Observations on the birds of West Virginia. By Alexander Wetmore. Pp. 401–441. August 24, 1937.

No. 3022. Annotated list of West Virginia mammals. By Remington Kellogg. Pp. 443–479. October 7, 1937.

No. 3023. On the detailed skull structure of a crested hadrosaurian dinosaur. By Charles W. Gilmore. Pp. 481–491, figs. 29–34. October 12, 1937.

No. 3024. Hydrocorals of the North Pacific Ocean. By Walter Kenrick Fisher. Pp. 493–554, pls. 34–76. March 8, 1938.

No. 3025. A giant new species of fairy shrimp of the genus *Branchinecta* from the State of Washington. By James E. Lynch. Pp. 555–562, pls. 77–80. December 3, 1937.

No. 3026. New species of moths of the family Notodontidae in the United States National Museum. By William Schaus. Pp. 563–584. December 29, 1937.

—— Title-page, table of contents, and index. Pp. i–viii, 585–606. June 18, 1938.

VOLUME 85

Separates:

No. 3027. On some onychophores from the West Indies and Central America. By Austin H. Clark. Pp. 1–3. November 5, 1937.

No. 3028. Synopsis of the beetles of the Chilean genus *Phytholaema* (Scarabaeidea: Melolonthinae). By Lawrence W. Saylor. Pp. 5–11, fig. 1. December 3, 1937.

No. 3029. Redescription of the capelin *Mallotus catervarius* (Pennant) of the North Pacific. By Leonard P. Schultz. Pp. 13–20. December 2, 1937.

No. 3030. A Miocene booby and other records from the Calvert formation of Maryland. By Alexander Wetmore. Pp. 21–25, figs. 2, 3. January 14, 1938.

No. 3031. Another fossil owl from the Eocene of Wyoming. By Alexander Wetmore. Pp. 27–29, figs. 4, 5. January 17, 1938.

No. 3032. Descriptions of new fishes obtained by the United States Bureau of Fisheries steamer *Albatross*, chiefly in Philippine and adjacent waters. By Henry W. Fowler. Pp. 31–135, figs. 6–61. May 23, 1938.

No. 3033. Evidence of Triassic insects in the Petrified Forest National Monument, Arizona. By M. V. Walker. Pp. 137–141, pls. 1–4. June 14, 1938.

No. 3034. Review of the annelid worms of the family Nephtyidae from the Northeast Pacific, with descriptions of five new species. By Olga Hartman. Pp. 143–158, figs. 62–67. June 8, 1938.

No. 3036. Revision of the Nearctic leafhoppers of the tribe Errhomenellini (Homoptera: Cicadellidae). By P. W. Oman. Pp. 163–180, pls. 5, 6. May 27, 1938.

No. 3037. A new genus and two new species of the dipterous family Phoridae. By Charles T. Greene. Pp. 181–185, fig. 69. June 27, 1938.

No. 3038. A new genus and two new species of cottoid fishes from the Aleutian Islands. By Leonard P. Schultz. Pp. 187–191, fig. 70. May 12, 1938.

BULLETINS

No. 166. The oxystomatous and allied crabs of America. By Mary J. Rathbun. vi+278 pp., 86 pls., 47 figs. October 14, 1937.

No. 168. Nearctic Collembola, or springtails, of the family Isotomidae. By J. W. Folsom. iii+144 pp., 39 pls. July 1, 1937.

No. 169. The Fort Union of the Crazy Mountain Field, Montana, and its mammalian fauna. By George Gaylord Simpson. x+387 pp., 10 pls., 80 figs. August 21, 1937.

No. 171. The Pleistocene vertebrate fauna from Cumberland Cave, Maryland. By James W. Gidley and C. Lewis Gazin. vi+99 pp., 10 pls., 50 figs. May 5, 1938.

Separate from Bulletin 100:

Vol. 6, part 9. The tree snails of the genus *Cochlostyla* of Mindoro Province, Philippine Islands. By Paul Bartsch. Pp. 373–533, pls. 94–120. February 26, 1938.

PUBLICATIONS OF THE BUREAU OF AMERICAN ETHNOLOGY

The editorial work of the bureau has continued under the immediate direction of the editor, Stanley Searles. During the year one annual report and three bulletins were issued as follows:

Fifty-fourth Annual Report of the Bureau of American Ethnology to the Secretary of the Smithsonian Institution, 1936–1937. 9 pp.

Bulletin 115. Journal of Rudolph Friederich Kurz. Edited by J. N. B. Hewitt. 382 pp., 48 pls.

Bulletin 116. Ancient caves of the Great Salt Lake region. By Julian H. Steward. 131 pp., 1 map, 9 pls., 48 figs.

Bulletin 117. Historical and ethnographical material on the Jivaro Indians. By M. W. Stirling. 148 pp., 1 map, 37 pls., 6 figs.

REPORT OF THE AMERICAN HISTORICAL ASSOCIATION

The annual reports of the American Historical Association are transmitted by the association to the Secretary of the Smithsonian Institution and are communicated by him to Congress, as provided by the act of incorporation of the association.

The report for 1933 (Writings on American History) and the report for 1936, volume 1, were issued during the year. The report for 1937 and Writings on American History, 1934 and 1935, were in press at the close of the year.

REPORT OF THE NATIONAL SOCIETY, DAUGHTERS OF THE AMERICAN REVOLUTION

The manuscript of the Fortieth Annual Report of the National Society, Daughters of the American Revolution, was transmitted to Congress, in accordance with law, December 3, 1937.

ALLOTMENTS FOR PRINTING

The congressional allotments for the printing of the Smithsonian Annual Reports to Congress and the various publications of the

Government bureaus under the administration of the Institution were virtually used up at the close of the year. The appropriation for the coming year ending June 30, 1939, totals $67,000, allotted as follows:

Smithsonian Institution	$17,000
National Museum	29,000
Bureau of American Ethnology	12,000
International Exchange Service	100
National Zoological Park	100
Astrophysical Observatory	400
American Historical Association	8,000
National Collection of Fine Arts	400

Respectfully submitted.

W. P. True, *Editor.*

Dr. C. G. Abbot,
Secretary, Smithsonian Institution.

REPORT OF THE EXECUTIVE COMMITTEE OF THE BOARD OF REGENTS OF THE SMITHSONIAN INSTITUTION

FOR THE YEAR ENDED JUNE 30, 1938

To the Board of Regents of the Smithsonian Institution:

Your executive committee respectfully submits the following report in relation to the funds of the Smithsonian Institution, together with a statement of the appropriations by Congress for the Government bureaus in the administrative charge of the Institution.

SMITHSONIAN ENDOWMENT FUND

The orginal bequest of James Smithson was £104,960 8s 6d—$508,318.46. Refunds of money expended in prosecution of the claim, freights, insurance, etc., together with payment into the fund of the sum of £5,015, which had been withheld during the lifetime of Madame de la Batut, brought the fund to the amount of	$550, 000. 00
Since the original bequest the Institution has received gifts from various sources chiefly in the years prior to 1893, the income from which may be used for the general work of the Institution. To these gifts has been added capital from savings on income, gain from sale of securities, etc., bringing the total endowment for general purposes to the amount of	1, 150, 703. 76

The Institution holds also a number of endowment gifts, the income of each being restricted to specific use. These are invested and stand on the books of the Institution as follows:

Abbott, William L., fund, bequest to the Institution	$101, 108. 02
Arthur, James, fund, income for investigations and study of sun and lecture on the sun	39, 689. 13
Bacon, Virginia Purdy, fund, for a traveling scholarship to investigate fauna of countries other than the United States	49, 719. 73
Baird, Lucy H., fund, for creating a memorial to Secretary Baird	14, 225. 49
Barstow, Frederic D., fund, for purchase of animals for the Zoological Park	754. 88
Canfield collection fund, for increase and care of the Canfield collection of minerals	37, 956. 16
Casey, Thomas L., fund, for maintenance of the Casey collection and promotion of researches relating to Coleoptera	7, 669. 52
Chamberlain, Francis Lea, fund, for increase and promotion of Isaac Lea collection of gems and mollusks	27, 946. 29
Hillyer, Virgil, fund, for increase and care of Virgil Hillyer collection of lighting objects	6, 522. 24
Hitchcock, Dr. Albert S., Library fund, for care of Hitchcock Agrostological Library	1, 190. 87
Hodgkins fund, specific, for increase and diffusion of more exact knowledge in regard to nature and properties of atmospheric air	100, 000. 00

Special research fund, gift, in form of real estate	$20,946.00
Hughes, Bruce, fund, to found Hughes alcove	15,034.83
Myer, Catherine Walden, fund, for purchase of first-class works of art for the use of, and benefit of, the National Gallery of Art	18,811.84
Pell, Cornelia Livingston, fund, for maintenance of Alfred Duane Pell collection	2,395.18
Poore, Lucy T. and George W., fund, for general use of the Institution when principal amounts to the sum of $250,000	71,535.89
Reid, Addison T., fund, for founding chair in biology in memory of Asher Tunis	28,981.48
Roebling fund, for care, improvement, and increase of Roebling collection of minerals	119,764.35
Rollins, Miriam and William, fund, for investigations in physics and chemistry	92,791.56
Springer, Frank, fund, for care, etc., of Springer collection and library	17,796.43
Walcott, Charles D., and Mary Vaux, research fund, for development of geological and paleontological studies and publishing results thereof	10,883.24
Younger, Helen Walcott, fund, held in trust	50,112.50
Zerbee, Frances Brincklé, fund, for endowment of aquaria	755.28
Total endowment for specific purposes other than Freer endowment	836,590.91

The capital funds of the Institution, except the Freer funds, are invested as follows:

Fund	United States Treasury	Consolidated fund	Separate fund	Total
Abbott, W. L.		$67,800.35	$33,307.67	$101,108.02
Arthur, James		39,689.13		39,689.13
Bacon, Virginia Purdy		49,719.73		49,719.73
Baird, Lucy H.		14,225.49		14,225.49
Barstow, Frederic D.		754.88		754.88
Canfield collection		37,956.16		37,956.16
Casey, Thomas L.		7,669.52		7,669.52
Chamberlain		27,946.29		27,946.29
Hillyer, Virgil		6,522.24		6,522.24
Hitchcock, Library		1,190.87		1,190.87
Hodgkins, specific	$100,000			100,000.00
Special research			20,946.00	20,946.00
Hughes, Bruce		15,034.83		15,034.83
Myer, Catherine W.		18,811.84		18,811.84
Pell, Cornelia Livingston		2,395.18		2,395.18
Poore, Lucy T., and George W.	26,670	44,865.89		71,535.89
Reid, Addison T.	11,000	13,481.48	4,500.00	28,981.48
Roebling collection		119,764.35		119,764.35
Rollins, Miriam and William		83,291.56	9,500.00	92,791.56
Smithsonian unrestricted:				
Special			1,400.00	1,400.00
Avery	14,000	36,953.44		50,953.44
Endowment		211,871.12		211,871.12
Habel	500			500.00
Hachenberg		3,990.90		3,990.90
Hamilton	2,500	400.61		2,900.61
Henry		1,200.21		1,200.21
Hodgkins (general)	116,000	29,993.12		145,993.12
Parent	727,640	1,211.48		728,851.48
Rhees	590	469.47		1,059.47
Sanford	1,100	883.41		1,983.41
Springer		17,796.43		17,796.43
Walcott, Charles D., and Mary Vaux		10,883.24		10,883.24
Younger, Helen Walcott			50,112.50	50,112.50
Zerbee, Frances Brincklé		755.28		755.28
Total	1,000,000	867,528.50	119,766.17	1,987,294.67

CONSOLIDATED FUND

Statement of principal and income for the last 10 years

Fiscal year	Capital	Income	Percentage
1929	$557,056.95	$28,109.56	5.04
1930	578,292.40	28,908.87	5.00
1931	668,069.02	28,518.07	4.27
1932	712,156.86	26,142.21	3.67
1933	764,077.67	28,185.11	3.68
1934	754,570.84	26,650.32	3.66
1935	706,765.68	26,808.86	3.79
1936	723,795.46	26,836.61	3.71
1937	738,858.54	33,819.43	4.57
1938	867,528.50	34,679.64	4.00

FREER GALLERY OF ART FUND

Early in 1906, by deed of gift, Charles L. Freer, of Detroit, gave to the Institution his collection of Chinese and other oriental objects of art, as well as paintings, etchings, and other works of art by Whistler, Thayer, Dewing, and other artists. Later he also gave funds for the construction of a building to house the collection, and finally in his will, probated November 6, 1919, he provided stock and securities to the estimated value of $1,958,591.42 as an endowment fund for the operation of the gallery. From the above date to the present time these funds have been increased by stock dividends, savings of income, etc., to a total of $4,820,777.31. In view of the importance and special nature of the gift and the requirements of the testator in respect to it, all Freer funds are kept separate from the other funds of the Institution, and the accounting in respect to them is stated separately.

The invested funds of the Freer bequest are classified as follows:

Court and grounds fund	$540,074.68
Court and grounds maintenance fund	135,782.17
Curator fund	549,589.39
Residuary legacy	3,595,331.07
Total	4,820,777.31

SUMMARY

Invested endowment for general purposes	$1,150,703.76
Invested endowment for specific purposes other than Freer endowment	836,590.91
Total invested endowment other than Freer endowment	1,987,294.67
Freer invested endowment for specific purposes	4,820,777.31
Total invested endowment for all purposes	6,808,071.98

CLASSIFICATION OF INVESTMENTS

Deposited in the U. S. Treasury at 6 percent per annum, as authorized in the United States Revised Statutes, sec. 5591		$1,000,000.00
Investments other than Freer endowment (cost or market value at date acquired):		
Bonds (25 different groups)	$328,855.55	
Stocks (50 different groups)	551,406.56	
Real estate and first-mortgage notes	75,053.67	
Uninvested capital	31,978.89	
		987,294.67
Total investments other than Freer endowment		1,987,294.67
Investments of Freer endowment (cost or market value at date acquired):		
Bonds (47 different groups)	$2,172,981.47	
Stocks (50 different groups)	2,449,317.39	
Real estate first-mortgage notes	9,000.00	
Uninvested capital	189,478.45	
		4,820,777.31
Total investments		6,808,071.98

CASH BALANCES, RECEIPTS, AND DISBURSEMENTS DURING THE FISCAL YEAR [1]

Cash balance on hand June 30, 1937		$354,294.70
Receipts:		
Cash income from various sources for general work of the Institution	$65,636.52	
Cash gifts and contributions expendable for special scientific objects (not to be invested)	51,032.50	
Cash gifts for special scientific work (to be invested)	44,803.58	
Cash income from endowments for specific use other than Freer endowment and from miscellaneous sources (including refund of temporary advances)	67,369.82	
Cash received as royalties from Smithsonian Scientific Series	42,195.73	
Cash capital from sale, call of securities, etc. (to be reinvested)	67,924.33	
Total receipts other than Freer endowment		338,962.48
Cash receipts from Freer endowment, income from investments, etc	$255,651.61	
Cash capital from sale, call of securities, etc. (to be reinvested)	544,896.45	
Total receipts from Freer endowment		800,548.06
Total		1,493,805.24

[1] This statement does not include Government appropriations under the administrative charge of the Institution.

Disbursements:		
From funds for general work of the Institution:		
Buildings—care, repairs, and alterations	$3,235.62	
Furniture and fixtures	225.84	
General administration [2]	28,540.66	
Library	2,224.07	
Publications (comprising preparation, printing, and distribution)	19,314.78	
Researches and explorations	31,446.60	
		$84,987.57
From funds for specific use, other than Freer endowment:		
Investments made from gifts, from gain from sale, etc., of securities and from savings on income	72,893.20	
Other expenditures, consisting largely of research work, travel, increase and care of special collections, etc., from income of endowment funds and from cash gifts for specific use (including temporary advances)	85,822.05	
Reinvestment of cash capital from sale, call of securities, etc	43,772.69	
Cost of handling securities, fee of investment counsel, and accrued interest on bonds purchased	1,775.50	
		204,263.44
From Freer endowment:		
Operating expenses of the gallery, salaries, field expenses, etc	57,859.40	
Purchase of art objects	170,039.96	
Investments made from gain from sale, etc., of securities	39,559.79	
Reinvestment of cash capital from sale, call of securities, etc	350,924.67	
Cost of handling securities, fee of investment counsel, and accrued interest on bonds purchased	19,677.72	
		638,061.54
Cash balance June 30, 1938		566,492.69
Total		1,493,805.24

[2] This includes salary of the Secretary and certain others.

EXPENDITURES FOR RESEARCHES IN PURE SCIENCE, PUBLICATIONS, EXPLORATIONS, CARE, INCREASE, AND STUDY OF COLLECTIONS, ETC.

Expenditures from general funds of the Institution:		
Publications	$19,314.78	
Researches and explorations	31,446.60	
		$50,761.38
Expenditures from funds devoted to specific purposes:		
Researches and explorations	58,400.78	
Care, increase, and study of special collections	10,191.15	
Publications	1,620.96	
		70,212.89
Total		120,974.27

The practice of depositing on time in local trust companies and banks such revenues as may be spared temporarily has been continued during the past year, and interest on these deposits has amounted to $903.14.

The Institution gratefully acknowledges gifts or bequests from the following:

Friends of Dr. Albert S. Hitchcock, for establishment and care of the Hitchcock Agrostological Library.

Research Corporation, further contributions for research in radiation.

John A. Roebling, further contributions for research in radiation.

Mrs. Mary Vaux Walcott, for purchase of certain specimens.

Laurence L. Wilson, for archeological investigations in Texas.

All payments are made by check, signed by the Secretary of the Institution on the Treasurer of the United States, and all revenues are deposited to the credit of the same account. In many instances deposits are placed in bank for convenience of collection and later are withdrawn in round amounts and deposited in the Treasury.

The foregoing report relates only to the private funds of the Institution.

The following annual appropriations were made by Congress for the Government bureaus under the administrative charge of the Smithsonian Institution for the fiscal year 1938:

Salaries and expenses		$36,330
International Exchanges		44,260
American Ethnology		58,730
Astrophysical Observatory		30,850
National Museum:		
Maintenance and operation	$144,840	
Preservation of collections	609,380	
		754,220
National Collection of Fine Arts		34,275
Printing and binding		65,000
National Zoological Park		225,000
Total		1,248,665

The report of the audit of the Smithsonian private funds is printed below:

SEPTEMBER 1, 1938.

EXECUTIVE COMMITTEE, BOARD OF REGENTS,
Smithsonian Institution, Washington, D. C.

SIRS: Pursuant to agreement we have audited the accounts of the Smithsonian Institution for the fiscal year ended June 30, 1938, and certify the balance of cash on hand, including Petty Cash Fund, June 30, 1938, to be $568,392.69.

We have verified the record of receipts and disbursements maintained by the Institution and the agreement of the book balances with the bank balances.

We have examined all the securities in the custody of the Institution and in the custody of the banks and found them to agree with the book records.

We have compared the stated income of such securities with the receipts of record and found them in agreement therewith.

We have examined all vouchers covering disbursements for account of the Institution during the fiscal year ended June 30, 1938, together with the authority therefor, and have compared them with the Institution's record of expenditures and found them to agree.

We have examined and verified the accounts of the Institution with each trust fund.

We found the books of account and records well and accurately kept and the securities conveniently filed and securely cared for.

All information requested by your auditors was promptly and courteously furnished.

We certify the balance sheet, in our opinion, correctly presents the financial condition of the Institution as at June 30, 1938.

Respectfully submitted.

WILLIAM L. YAEGER & CO.,
WILLIAM L. YAEGER,
Certified Public Accountant.

Respectfully submitted.

FREDERIC A. DELANO,
R. WALTON MOORE,
JOHN C. MERRIAM,
Executive Committee.

GENERAL APPENDIX

TO THE

SMITHSONIAN REPORT FOR 1938

ADVERTISEMENT

The object of the General Appendix to the Annual Report of the Smithsonian Institution is to furnish brief accounts of scientific discovery in particular directions; reports of investigations made by collaborators of the Institution; and memoirs of a general character or on special topics that are of interest or value to the numerous correspondents of the Institution.

It has been a prominent object of the Board of Regents of the Smithsonian Institution from a very early date to enrich the annual report required of them by law with memoirs illustrating the more remarkable and important developments in physical and biological discovery, as well as showing the general character of the operations of the Institution; and, during the greater part of its history, this purpose has been carried out largely by the publication of such papers as would possess an interest to all attracted by scientific progress.

In 1880, induced in part by the discontinuance of an annual summary of progress which for 30 years previously had been issued by well-known private publishing firms, the secretary had a series of abstracts prepared by competent collaborators, showing concisely the prominent features of recent scientific progress in astronomy, geology, meteorology, physics, chemistry, mineralogy, botany, zoology, and anthropology. This latter plan was continued, though not altogether satisfactorily, down to and including the year 1888.

In the report for 1889 a return was made to the earlier method of presenting a miscellaneous selection of papers (some of them original) embracing a considerable range of scientific investigation and discussion. This method has been continued in the present report for 1938.

NEW CONCEPTIONS OF THE UNIVERSE AND OF MATTER [1]

By Gabriel Louis-Jaray

The principles of physics appear to have been entirely reconstructed since the beginning of the twentieth century; because of experiments made during the past 30 years, new ideas prevail in this science; man is endeavoring to explain the universe, the atom, matter, light according to conceptions essentially different from those of the nineteenth century.

Louis de Broglie asserts that the introduction into physics in 1900 of the observations of Planck marks "one of the most important moments in the evolution of contemporaneous science." [2] In promoting that evolution a great number of French scholars have labored and the "Palace of Discovery" exhibits some of their researches.

The efforts of physicists have been directed especially toward the study of the infinitely small and of the infinitely large: Astrophysicists have pushed their stellar observations to extraordinary distances and atomic physics has succeeded in revealing the orbit of an element of matter of which 10 million could be placed end to end in a millimeter. In one case as in the other, these studies require the use of a laboratory equipment that can only be attained with an infinite amount of care, time, and money. This is one of the reasons which explain why so many years were needed to bring out the new discoveries, a glimpse of which we will try to present.

The older physics was founded upon the existence of simple elements, not transmutable, of which today there are 92. Alchemy and the older physics had failed in the search for unity in matter.

The new physics considers that matter is composed of atoms all formed essentially of two parts: A nucleus, called a proton, around which revolves one or several corpuscles called electrons; the most simple element is hydrogen, of which the nucleus is formed of a single proton, around which a single electron revolves; by changing the number and the arrangement of these two elements of the atom we obtain the 92 simple elements. Efforts to transmute artificially from one element to another have succeeded. Thus the new physics is founded upon a real unity of matter.

---

[1] Translated by permission from Mercure de France, vol. 283, No. 956, April 15, 1938.

[2] Louis de Broglie: Matière et lumière, Paris, Albin Michel, p. 278, 1937.

Nevertheless, there is uncertainty regarding the elements of this unity. It was thought until very recently that all atoms could be reduced to a nucleus composed of protons of positive electricity (each proton having a mass 2,000 times greater than an electron) and of electrons of negative electricity; the infinitely small atom appeared to be a sun in miniature with his planet or planets, and matter seemed composed of electrified particles oscillating in space; Thibaut, director of the institute of atomic physics of the University of Lyon, supposes, in order to visualize the atom, that the atom of hydrogen be as big as the whole of Paris; the nucleus would be the size of the Arc de Triomphe, the electron would be represented by a billiard ball situated in the Place de la Concorde and the remainder of the atom would be empty space.[3]

But in these last years, the profound studies of matter from every angle have more and more complicated the problem. Much uncertainty exists; in effect man has discovered: First, an electron of positive electricity (called a positron), very difficult to obtain, which scarcely born, seems to unite with other particles; its size is similar to that of the negative electron, of which it is the brother; second, a particle called the neutron, thus named because it is not electrified; it is analogous to the proton in mass (2,000 times that of the electron) and sometimes unites with the nucleus of the atom; third, a fifth mysterious particle called a neutrino, because it is not electrified; it is neutral like the neutron, but with a mass as small as the electron, perhaps even smaller and almost negligible.

Our impression is that the new physics is still in its infancy. Some physicists conceive of matter as electrified particles surrounded by empty space; Thibaud asks whether the neutron cannot be separated into two corpuscles, one positive and the other negative, and whether the "hypothetical neutrino," as he calls it, would not be the accompaniment of such a breaking up.[4] Louis de Broglie looks with more favor on the breaking up of the proton into neutron and positive electron.[5] Thus, according to this last authority, the atom and matter are compounded of three elements: neutrons, not electrified, possessing nearly all the mass, negative electrons and positive electrons both of very small mass but electrified.

Nevertheless, the new physics is plainly built upon the idea of the unity of matter.

---

[3] Physicists and astrophysicists know but little about empty space in the atom or between celestial bodies; they no longer believe in the "ether" of Fresnel. The astronomer Esclangon conceives space not as nothingness but as an entity, furrowed with radiations, composed perhaps of unknown elements which constitute a substratum of matter and radiation, capable of reactions similar to those of matter.

[4] Thibaud, Jean, Vie et transmutation des atomes, p. 110, Paris, Albin Michel, 1937.

[5] Matière et lumière, p. 32.

The new physics differs essentially from the old in other respects: The old mechanics had its dogmas; no velocity could be greater than that of light; no temperature could be less than zero degrees absolute; matter could not be destroyed, etc.; this last law is no longer recognized. Most of the outstanding physicists, such as Eddington, admit "the annihilation of matter" though it seems apparently supernatural. One experiment shows that pairs of positive and negative electrons are destroyed and produce pairs of photons of light, and in the opposite sense the photons [6] produce pairs of positive and negative electrons; the first case appears to be a "dematerialization" and the second case a "materialization," if the electrons are very small corpuscles but material parts of the atom and if the photons, that is the radiations, are not material corpuscles. Thus, says Einstein, in place of the principle of the conservation of matter and of the conservation of energy, it is necessary to substitute a simple principle of equivalence, that of the "conservation of something," but permitting the conversion of matter into energy and energy into matter. An example shows this new conception in concrete fashion: An atom of helium is formed from four atoms of hydrogen; but the mass of the helium is less by a small quantity than the sum of four atoms of hydrogen; this small quantity of matter has changed into energy and the clamping together of the four atoms has liberated, it is said, 27 millions of volts; thus the loss of mass, or loss of matter, is compensated, according to the principle of equivalence, by the creation of energy.

Thibaud interprets the results of such experiments as just described by conceiving that it is the continuous destruction of matter in the sun which liberates the luminous radiation.[7] In any case one can imagine throughout the universe the transformation of atoms of sidereal bodies into radiation, as in radioactivity, or the transformation of radiation into matter as in the experiment with photons of gamma rays.

One difficulty remains: We do not know with certainty what the "photons" are, i. e., what light is. Louis de Broglie some 10 years ago conceived, and soon the new physics adopted, his "wave mechanics," applied first to light and then to all forms of energy. Newton asserted that light consisted of an emission of corpuscles, Fresnel that it consisted of waves in a tenuous medium, the ether, the existence of which modern physicists doubt, Louis de Broglie reunited the two theories and declared that what happens is wave motion and emission at the same time, light waves and the projection of corpuscles of light, called photons. Passing from light to matter, he asserted that it is necessary to link together the idea of a wave with the movement of material particles of the atom; the displacement of the material

[6] In the experiment, the photons are produced by a radiation called gamma rays.

[7] Vie et transmutation des atomes, p. 55.

114728—39——10

corpuscles is associated with a certain periodic phenomenon called a wave.

According to physicists, this generalized hypothesis to account for light and matter by wave mechanics explains all the recent experiments which the older physics failed to explain. But it makes a great mystery of physics; in a memoire, written in collaboration by Maurice de Broglie and Louis de Broglie, we read that the photon is a corpuscle of light whose nature remains very mysterious: Wave mechanics associates with motion "the consideration of a wave, without physical reality, but which can be predicted."[8]

In any case, in the new physics, to the idea of the unity of matter and of the interchangeability of energy and matter, it is necessary to add the idea that, for light and for matter, one must always "consider both the corpuscular aspect and the wave aspect, bound together by the same general relations";[9] we come thus to the "unitarian theory of matter and of light"; Louis de Broglie obtains this unity by the hypothesis that the neutrino, the last born of the constituent particles of matter, a corpuscle as small as or smaller than the electron and having "zero or at least a negligible charge in comparison with that of an electron," may be one of two constituents of the photon, the other being another corpuscle; he calls the neutrino a demiphoton;[10] but if the neutrino has a "physical entity" the photon becomes a material corpuscle and not simply a corpuscle of immaterial light.

We perceive, by these simple indications, to what extent the new physics is still mysterious and how it tends toward unity. It gives at times the impression that all material reality, in the older sense of the word, has disappeared and in its place there is substituted that which one might call a unique substance having corpuscular atomic form and possessing interchangeable attributes of mass and of energy. It seems to lead thus to a kind of materialistic "monism," outside of which the mysteries of life and of mind exist.

In short, the new physics is distinguished from the old in that it adopts conceptions which destroy the rigorous and universal determinism of mechanics and the principle of continuity.

Atomic physics, it tells us, shows a discontinuous reality, with abrupt transitions, which can only be explained "by the artifice of waves associated" with the motions of corpuscles. The introduction into physics, says Louis de Broglie, about 1900, by Planck, of the quantum of action and of the constant "h" is the origin of the change of view; let us then analyze each of these two new ideas.

The "quanta" of Planck can be roughly explained by indicating that the radiation of atoms is not continuous; apparently the energy

[8] Matière et lumière, pp. 59 and 60.
[9] Matière et lumière, p. 147.
[10] Op. cit., p. 153 and following.

accumulates until a certain quantity is stored up; when this quantity is reached, the radiation is emitted. Thus the radiation emanating from the atom is not considered as a continuous outpouring, but as a discontinuous emission of grains. Innumerable experiments since 1900 have shown that this quantity, called a "quantum," is proportional to the frequency of the radiation and not to its intensity. Maurice de Broglie has invented an apparatus for measuring the velocity of corpuscles (electrons) torn away from matter by the action of X-rays, which gives an experimental test of this "quantum" theory of Planck.[11] Physics is thus thrown into confusion by the substitution in the microscopic domain of the principle of discontinuity in place of the principle of continuity.

Leibnitz said that nature does not make jumps: *Natura non facit saltus;* in the world of atoms, modern physics perceives nothing but jumps. Atomic physics limits itself to uncovering the laws which govern these jumps; it observes only the value, the quantum of energy; it seeks to calculate the probability that an atomic system existing at a given moment will find itself subsequently in such or such other state; and atomic physics finds that these laws are only the laws of probability. From the moment that one starts with the discontinuous action of elementary corpuscles of matter and of light, one cannot know whether at a given moment one of these corpuscles has or ought to have a certain precise position in space or a certain strictly defined motion; atomic physics declares it is impossible "to predict the future motion of a corpuscle of an atom." Indetermination is substituted for determinism; it is the "constant h" of Planck, the "uncertainty principle of Heinsenberg." All the experiments relative to "quanta" for 30 years are affected by an unknown, an indeterminate element that must be introduced to make the calculations succeed. This indeterminate constant has been represented by h, and it is even to this day susceptible of no interpretation. All the determinism of the mechanics of Newton is thus as if undermined at its base. "The significance (of this constant)," says Louis de Broglie, "has been for 30 years and still is today the enigma of modern physics; it has remained the undefinable syllable in nature's cross-word puzzle." This fundamental indeterminism appears as a sort of free choice of nature, escaping thus from the rigorous law of mechanics.

It is scarcely necessary to add that this introduction of discontinuity and indeterminism into physics is valid for the whole universe; but the indeterminate constant, represented by h in the calculations, is very small. Consequently, in the phenomena having to do with man or the stars, it is negligible. A margin of uncertainty always exists, but since it is less than the unavoidable errors which affect all observa-

[11] Vie et transmutation des atomes, p. 161; the application of this effect called "photoelectric" is utilized in television and in moving picture talking films.

tions, determinism is apparently maintained. In a way, the older physics remains approximately exact for man and for heavenly bodies; but it is powerless to determine at the same time with exactitude the position and velocity of an electron at a given moment and to predict with certainty its rigorously determined motion; discontinuity and indeterminism are integral parts of the atomic world.

Astrophysicists and physicists who study atomic structure must use their imagination; it is imagination which leads to experimentation and interpretation. But it is necessary at the same time to be prudent in this respect; the ascribed interpretations are usually afterward rejected.

New ideas can only be accepted as a result of conclusive and repeated experiment. Especially is it necessary always to distinguish carefully between the results of experiments and the interpretation given these results.

Thus, in astrophysics, since the work of Hubble in 1925, we consider that the spiral nebulae visible through our telescopes are island universes, analogous to the universe of which the earth, the sun, the Milky Way, and all the ordinary stars are a part and which we call "the galaxy."

The velocities of about 100 of these distant spiral nebulae are believed to have been determined, principally with the aid of the large Mount Wilson telescope; it appears from this work that all are moving away from us and with velocities as great as one-seventh of the velocity of light. Moreover, Hubble presented in 1929 a law according to which the velocity of recession is proportional to the distance; each increase of 1 million light-years in distance increases the velocity of recession by 170 kilometers per second. Thus all the galaxies appear to be running away from each other; they are fleeing from each other with increasing speed; it is this conclusion which gives us the term "the expanding universe," and suggests to us that the universe has doubled its radius in less than 2 billion years.[12] But when the galaxies will have attained a velocity as great as that of light, they can never be seen by man, for light rays from them will be unable to reach the earth. This will mean an unfathomable universe.

Of course, this interpretation rests upon the shift of lines in the spectra of spiral nebulae examined through the Mount Wilson telescope. Who can say that this shift of spectral lines will not soon be interpreted differently? The study of spectra is sufficiently mysterious for the whole interpretation to be taken with reservations.[13] Moreover, the strangest feature about Hubble's law is that it assumes

---

[12] See Paul Couderc, Univers 1937, Paris, Editions rationalistes, 1937.

[13] The astronomer Esclangon, for example, does not agree that light is absolutely constant and believes that measures relative to the light of stars are different from terrestrial measures; these conceptions, moreover, may be connected with those relating to interstellar space.

for distant galaxies in no way related to our galaxy, any law whatsoever which governs the life of all galaxies by comparison with our own.

One other hypothesis of astrophysicists seeks to solve the contradiction between the finite and the infinite; they call it the "curved universe." Curvature, sphericity, is to be the law of matter. The universe is shaped like an immense sphere, an enormous bubble; all radiation follows a curve; light coming to us from distant galaxies is bent. In consequence, light from a star ought to arrive at the earth from two opposite sides, from one side by the direct curve and from the other by making the complete circuit of the sphere. Let us await experimental proof that the propagation of radiation, energy, or light is not in a straight line but a curved path.

Without letting ourselves be carried away by imagination, let us realize that the tests of the past 30 years have led physicists to modify entirely their conceptions of the world, of light, of matter, of energy, of the universe. The infinitely great and the infinitely small seem immeasurable; they are not of the same order of magnitude as man. The mind asks, at each stage, whether these discoveries are not only symbols, constructions of the mind, whether they correspond to something entirely objective. At every moment one is tempted to say: "This happens as if"; but one dares only say: "This happens thus." At any rate, the new physics is the creator of mysteries. These are mysteries: The microscopic and the macroscopic, the indeterminism, the discontinuity, elements which change from one substance into another with the disappearance of part of their mass, the conversion of matter into energy and energy into matter. In place of the older, rigid mechanics, with the unalterable conservation of matter, with all motion determinate, with elements whose positions and velocities were known repeating themselves in "the form and motion" of Descartes, there is substituted a new physics which is directed by new views concerning the unity of matter and light, the principle of equivalence including the conversion of energy into matter and matter into energy, the introduction of discontinuity and indeterminism by wave machanics. These views completely change our conceptions of the exterior world and of the universe.

THE NATURE OF THE NEBULAE[1]

By Edwin Hubble

[With one plate]

The exploration of space is an achievement of great telescopes. Men first studied the heavens with their naked eyes. They recognized and described the solar system—the central sun with its family of planets—and the discovery is one of the great intellectual feats of the race. But beyond the planets lay the stars. They were too distant for reliable investigation, and their nature remained a subject of sheer speculation.

For the human eye, with all its perfection, is necessarily a small instrument; the aperture of the fully opened pupil is only a fifth of an inch. Many an astronomer, in those early days, must have dreamed of a giant's eye that would collect more light, penetrate more deeply into the universe around us. And eventually, that incredible dream materialized. Just 330 years ago the telescope, newly invented, was pointed toward the sky, and the way for exploration on the grand scale was suddenly opened. Galileo, as Kepler wrote to him, had scaled the very walls of heaven.

The centuries that followed were crowded with investigations that led to the formulation of modern astronomy. Telescopes and their accessories developed and, with each advance, new fields were opened. The nature of the stars was established. The sun itself was definitely recognized as a star, and earlier speculation on the subject was thus confirmed. The many millions of stars, it was found, are not scattered indefinitely through the universe; they form an isolated system. This swarm of stars, this stellar system, drifts through space. From our position somewhere within the system, we look out through the swarm of stars, past the borders, into the universe beyond.

Telescopes have continued to develop until today we are exploring those outer regions. They are inhabited by stellar systems comparable with our system of the Milky Way. Those other systems are the extragalactic nebulae. We find them scattered thinly through space out as far as telescopes can reach. They are gigantic beacons, permitting us to survey and study a sample of the universe. Even-

[1] Public lecture delivered in San Francisco, Monday evening, March 21, 1938, on the occasion of the presentation of the Bruce Gold Medal of the Astronomical Society of the Pacific. Reprinted by permission from The Publications of the Astronomical Society of the Pacific, vol. 50, No. 293, April 1938.

tually, if the sample is fair, we may be able to infer the nature of the universe as a whole from the observed characteristics of the sample available for inspection. This possibility is the ultimate goal of the explorations of space. The sample must be fair, and the characteristics must be determined with precision. How near we are to the realization of these conditions, we do not know, but we like to believe that the new telescope—the 200-inch reflector destined for Mount Palomar—may furnish an answer.

Meanwhile it is imperative to learn as much as possible with existing instruments, concerning the nature of the inhabitants of space. The nebulae are the landmarks that must necessarily be used in the general study. The more intimately we know their characteristics—their luminosities, dimensions, masses, structures and contents—the more reliably can we interpret the reports of the final surveys.

Our present information is still fragmentary, but by piecing bits together we can construct a fairly coherent picture. The nebulae, it is found, are all members of a single family. The forms vary widely but they fall readily into a sequence which represents the progressive variation of a single fundamental pattern. Thus it is possible to reduce the nebulae to a standard type, and to study them as one homogeneous group; or, it is possible to select conspicuous, neighboring nebulae, and to present them as typical examples of the family. In the discussion which follows, the latter alternative will be adopted.

THE LOCAL GROUP

On the grand scale, the nebulae are scattered more or less at random; one large volume of space is much like another. Nevertheless, the small scale distribution is quite irregular, and presents many analogies with the distribution of stars. Thus we find isolated nebulae, multiples, groups, clusters, and, possibly, clouds. Our own stellar system is the chief component of a triple nebula, the Magellanic Clouds playing the role of satellites. The great neighboring spiral in Andromeda is also favored with two satellites. These two triple systems, together with four or five other nebulae, form a loose group more or less isolated in the general field. The local group has played an important role in the development of nebular research for it furnished a small sample collection of nebulae so near that their brighter stars could be studied with existing telescopes. These stars, and, in particular, the Cepheid variables, furnished the criteria which established the scale of distances, and thereby opened the realm of the nebulae to actual exploration.

MESSIER 31

Except for our own stellar system, the most conspicuous member of the local group is the great spiral in Andromeda, M31, with its two satellites, M32 and NGC205. The spiral can be seen with the naked eye as a faint cloud about half the size of the moon, and with a total luminosity equal to that of a fourth- or fifth-magnitude star. When photographed with telescopes, the cloud takes shape as an elliptical object whose long diameter is above five times that of the moon, and whose ratio of axes is about 3 or 4 to 1. The central region is relatively bright but the luminosity fades outward to poorly defined edges. The spiral pattern has never been seen with any telescope, although it is easily recognized on the photographic plate. The image increases with the focal length of the telescope, ranging from perhaps a quarter-inch with small kodaks to about 6 feet at the Cassegrain focus of the 100-inch reflector. Thus, with powerful instruments, the nebula must be explored section by section. Our detailed information, at present, is restricted to selected areas, chosen for specific purposes. Photographs show a semistellar nucleus of about the fourteenth magnitude, surrounded by a central region of structureless, unresolved nebulosity, from which two arms emerge on opposite sides and wind outward to form the spiral pattern. The general pattern is repeated over and over among the fainter nebulae in the sky, and the variations are largely concerned with the relative amount of luminous material in the arms as compared with that in the central region. On the basis of this criterion, the normal spirals fall into a progressive sequence with M31 near the middle. In other words, M31 is a typical example of the intermediate type spirals. By analogy with other members of the class, we may safely conclude that the elliptical form of the image is an effect of foreshortening. The fundamental plane of the thin lens-shaped spiral is tilted about 15° from the line of sight.

The outer regions of the spiral arms, in contrast to the nuclear region, are partially resolved into separate stars—presumably the brighter giants and supergiants of a stellar system comparable with our own galactic system. On this assumption, the unresolved portions of the arms and the nuclear region consist of swarms of stars too faint to be seen individually. The fragmentary data now available, such as the stellar outbursts called novae, and the solar-type spectrum, are thoroughly consistent with this interpretation. The recognition of stars in the outer regions was the clue which solved the mystery of the distance. Various types of stars were recognized which are well known in our own system. Among other characteristics, we knew their intrinsic luminosities, or candlepowers, and, consequently, their apparent faintness indicated the distance of the nebula in which they were located. Once the distance (about 700,000 light-years) was

determined, the real dimensions of the system were readily calculated from the apparent dimensions.

The main body of the spiral, the portion that is conspicuous on well-exposed photographs, has a diameter of about 35,000 to 40,000 light-years, and a total luminosity of the order of 1,000 million suns. Extremely faint outer regions, whose existence can be detected by refined methods of investigation, more than double the over-all diameter, and add perhaps 60 percent to the luminosity. Thus, the spiral is revealed as a giant nebula, the greatest of all those whose individual distances are known, and comparable with the galactic system itself. It is surprising and even disturbing to find the two greatest known systems both within the local group but, on the basis of our present information, the conclusion seems unavoidable. To this extent we seem to inhabit a favored position in the universe.

The mass of so immense a system as M31 must also be abnormally large, although the precise quantity has not been determined. The spiral is rotating, and the speed of rotation can be measured with the spectrograph, but, as Zwicky has shown, such data alone do not furnish an unambiguous value of the mass—they may suggest, at best, only a lower limit. The relative, presumably orbital motions of the satellites bear directly on the problem, but we can measure only one component (namely, that in the line of sight) and, moreover, the planes of the orbits together with the protection factors are unknown. Finally, we can suppose that, among stellar systems in general, there exists a characteristic relation between total mass and total luminosity which may be evaluated with the aid of data from the galactic system. This method also is uncertain because it involves several unverified assumptions such as the detailed similarity of stellar contents and the ratio of dark to luminous material. Nevertheless, the different methods, none of them individually reliable, agree in suggesting a mass of the general order of 100,000 million suns, and we are inclined to believe that the number of ciphers is about correct.

MESSIER 32

The two satellites of the giant spiral are both fainter than the average nebula, and one of them, NGC205, is one of the faintest of the known dwarfs. In other words, the triple system covers practically the whole observed range in total luminosities, namely, six magnitudes, or about 1 to 250. The brighter satellite, M32, is superposed on the outer arm of the main spiral, about 24′ south of the nucleus. The actual location in the line of sight is a matter of speculation. M32 is not a spiral but is a typical example of an elliptical nebula (E2) with a ratio of axes about 8 to 10. It exhibits no structure save for the smooth fading of the luminosity from the

nucleus outward to undefined borders. The size of the image increases steadily with exposure times (the isophotal contours remaining similar ellipses), as far as the exposures have been pushed. Although the dimensions have little meaning apart from the observing conditions, the values usually quoted are a major diameter of 4′ or 800 light-years, and a total luminosity of the order of 20 million suns. The values refer to the conspicuous portion of the image on well-exposed photographs.

Very short exposures with the 100-inch telescope show a round, semistellar nucleus, about 2″ in diameter and about 13.4 magnitude. This diameter merely reflects the resolving power of the photographic plate, for visual examination shows a still smaller nucleus. Sinclair Smith, using an interferometer on the 100-inch, found no trace of a strictly stellar center, and concluded that the true nucleus is probably a globular mass with a diameter of perhaps 0″.8, or about 2 light-years. The concentration of luminosity within such a nucleus would be somewhat greater than that in the central region of the most compact globular cluster—in other words, not inconsistent with the assumption that the nebula is a system of stars.

The nucleus of M32 has been described at some length because, as far as observations go, it appears to be typical of nebulae in general, and, being relatively near, can be studied in greater detail. The nucleus of our own system is presumably hidden behind dark obscuring clouds in the Milky Way. Baade, using red-sensitive plates and heavy filters, has partially penetrated the clouds, and, in the direction of the galactic center and at latitude 4°, has recorded a star-density which is of the order of 800,000 per square degree. Such a density at perhaps 2,000 light-years from the actual center requires no unreasonable extrapolation to suggest a nuclear density comparable with those in M32 and M31.

Since the satellite is superposed on the outer, partially resolved region of the main spiral, the search for individual stars is somewhat confused. It can be stated that there is no definite trace of resolution in the satellite, and, consequently, there are probably no supergiants in the system. The available photographs probably establish this conclusion down to $M=-2$, and possibly to $M=-1$. Nevertheless, Sinclair Smith's investigations indicate that the assumption of a stellar constitution offers the most plausible and consistent working hypothesis that has been formulated. Thus we are presented with the problem of a stellar system in which supergiants are not present.

The problem assumes general significance because the satellite closely resembles the nuclear region of the main spiral in color and spectrum as well as texture, and both nebulae, as previously mentioned, are typical examples of their classes. The spiral exhibits a

complementary distribution—supergiants in the outer region, dwarfs and (possibly) giants in the nuclear region. Among nebulae in general, the relative distribution varies systematically through the sequence of structural forms, the supergiants working inward as the spirals unwind. The characteristic behavior offers a possible observational approach to the fundamental question of nebular evolution, the first problem being a study of the systematic variation in stellar contents of nebulae along the sequence of forms. This problem requires the greatest possible light-gathering power and will be especially suitable for the 200-inch reflector when that telescope is completed. Meanwhile, the preliminary investigations are carried on with the 100-inch, and some of the results for M31 will presently be discussed.

NGC205

First, however, some mention should be made of the third member of the triple system, the fainter satellite, NGC205. It lies about 37′ north preceding the nucleus of the main spiral, almost exactly along the minor axis. As in the case of M32, the actual position in the line of sight is wholly speculative. However, the radial velocity is appreciably the same as that of the spiral, and, consequently, the orbital motion must be almost entirely across the line of sight. This situation is consistent with the assumption that the satellite may lie close to the fundamental plane of the spiral. The distance between the two nuclei would then be of the order of 30,000 light-years, and the satellite would be located within the extremely faint, tenuous, outer extensions of the spiral.

NGC205 is a nondescript system. In form and general texture, it resembles an elliptical type (E5) with a ratio of axes about 2 to 1, but the concentration toward the center is very low, small obscuring clouds are involved, and several individual stars and small nebulous objects (presumably globular clusters) seem to be associated with the satellite. The dimensions, as usual, vary with exposures, but the diameters are generally quoted as $8' \times 4'$ or $1,600 \times 800$ light-years, and the total luminosity as about 7 million suns.

STELLAR CONTENTS OF MESSIER 31

OBSCURATION

Since the two satellites are unresolved, the main spiral alone offers an opportunity to examine the stellar contents of a nebula. The investigation reveals many analogies with the galactic system, consistent with the current picture of our own nebula as a spiral at a stage in the sequence somewhat later than M31. One of the most conspicuous features is the great amount of obscuration. The

extreme north following end of the spiral is lightly veiled, and the central half of the nebula, north preceding the major axis, is fainter than the south following half. The latter feature is frequently used in attempts to determine the true orientation—to identify the side of the nebula which is nearest the observer. The question is still unanswered, and with it another fundamental question concerning the direction of rotation—whether the spiral is "winding up" or "unwinding."

In addition to the veiling of large areas, many obscuring clouds are scattered over the nebula. The absorption has not been measured, but it seems likely that the "all or none" principle is approximated. On the one hand, certain clouds seem to exhibit complete absorption and, moreover, the spiral obscures the faint, distant, background nebulae in a very conspicuous manner. On the other hand, stars of various known types, widely scattered over the spiral, exhibit only the normal dispersion about their mean luminosities, and the behavior suggests that the systematic effects of absorption on these particular stars are either negligible or curiously uniform. The question of absorption is important and deserves further investigation, for it is one of the factors involved in the precise determination of the distance of the nebula. At present the effect is ignored in the calculations but is recognized as an uncertainty which operates in a specific direction.

STAR CLOUDS AND OPEN CLUSTERS

The upper limit of stellar luminosities in M31 is probably of the order of $M = -6$, or somewhat fainter than the corresponding limit in the galactic system. Stars brighter than $M = -5$ are not numerous, but thereafter the numbers increase rapidly with diminishing luminosity as would be expected in a great stellar system. The distribution of the supergiants (the only stars which can be studied individually) follows the spiral arms much as, in our own system, they follow the Milky Way. Star clouds are conspicuous; one, for instance, was listed in the early catalogs as a separate nebula, NGC206. Open clusters are also found, and in at least one case a typical A-type spectrum has been recorded. Emission nebulosities (of the type of the Orion nebula) have not been recognized; but such objects are known to be a characteristic feature of later type spirals, and their absence in M31 is expected.

CEPHEIDS

Three types of objects have been found in large numbers and studied in some detail, namely, Cepheid variables, novae, and globular clusters. The first Cepheid was discovered in 1923; systematic

investigations during the next 5 years increased the number to 40, and a dozen or more have since been added to the list. The light-curves are typical and the periods, with one outstanding exception ($P=175$ days), range from 48 to 10 days. The data exhibit the familiar relation between periods and mean, or maximum, luminosities—the famous period-luminosity relation—by virtue of which the Cepheids furnish the best available criterion of great distances. Wherever we find Cepheids, their periods indicate their intrinsic luminosities (candlepowers) and, consequently, their apparent faintness measures their distances. For instance, the known Cepheids in M31, as indicated by their periods, average about 1,800 times as bright as the sun, but they appear about 200,000 times fainter than the faintest stars seen with the naked eye.

The distance of M31 would be rather accurately determined by this method if it were not for the uncertain effects of obscuration, both in the galactic system and in the spiral. The main body of the galactic system appears to be embedded in a widespread, tenuous medium (often called the uniform layer), and, of course, many clouds of dust and gas are scattered through the system, concentrating toward the fundamental plane of the Milky Way. From our position within the system, and close to the galactic plane, we observe distant nebulae through the surrounding haze and between the obscuring clouds. The absorption is greatest in and near the Milky Way, and diminishes toward the galactic poles. But the effects are not strictly uniform as we look around the sky at a given galactic latitude, and the calculated corrections, at present, represent average values which may not be precise for a particular direction.

Now M31 is seen near the edge of the Milky Way at latitude 20°. The average obscuration at this latitude is about 0.48 magnitude (55 percent) but the proper correction might be considerably different. Actually, the large numbers of very faint, distant nebulae found in the vicinity of M31 suggest that the region is more transparent than normal. A cloud, or real aggregation of the background nebulae, would produce the same phenomenon, and it is quite possible that both effects are present. However, an examination of the data leads to the provisional conclusion that abnormal transparency is the dominating factor, and, consequently, the effect will be partially compensated by minor obscuration within the spiral. These remarks sufficiently indicate that the precise effect of obscuration is an unsolved problem. For the present, it is advisable to apply the average correction for galactic latitude, and to recognize an uncertainty of the order of 10 to 25 percent in the resulting distance.

The direct procedure is then to compare the many Cepheids in M31 with those in the Small Magellanic Cloud which serves as a unit of extragalactic distance. Taking account of the average galactic ob-

scuration in the two directions, we find that the Cepheids in M31 average about 4.3 magnitudes fainter than Cepheids with corresponding periods in the Cloud. Therefore, the relative distances are about 7.2 to 1. Since the current value for the distance of the Cloud is 95,000 light-years, the distance of the spiral is about 700,000 light-years, subject to the previously mentioned uncertainty.

NORMAL NOVAE

About 120 normal novae have been discovered in M31 during the past 21 years. The record is by no means complete, for an analysis of the well-observed seasons suggests that the frequency is of the order of 25 to 30 per year. These novae form a very homogeneous group; their light curves are more or less similar over the regions that can be observed, and the dispersion about the mean luminosities at corresponding stages is remarkably small.

A discussion of the data some 10 years ago suggested a mean luminosity at maximum of the order of $M=-5.7$ with a dispersion of about 0.5 magnitude. The mean light-curve for the first month after maximum appeared to be approximately linear with a slope of the order of 0.05 magnitude per day. Spectra of two novae, obtained by Humason in 1932, exhibited the familiar features of normal novae in the galactic system.

The general similarity to galactic novae is pronounced, but a detailed comparison of maximum luminosities leads to discrepancies. Galactic novae, as a class, are systematically brighter by more than a magnitude. Moreover, several cases are known—e. g., Nova Aquilae (1918), Nova Persei (1901), T Scorpii (1860)—where the maxima were of the order of $M=-9$, which would be highly improbable on the basis of the small dispersion about the mean maximum derived in M31.

The study of galactic novae, as a class, is subject to effects of selection which favor the brighter objects, and to difficulties of measuring individual distances. For these reasons, it was hoped that the group characteristics could be determined in the neighboring spiral, and the results used in the interpretation of observations within the galactic system. The procedure cannot be followed unless the two groups of novae are known to be strictly comparable. Thus the apparent discrepancies assumed unusual importance; they indicated either intrinsic differences between the groups or errors in the interpretation of the available data, and no progress was possible until the question was settled.

Quite recently, my colleague, Dr. Baade, has found a solution in the latter alternative. Observations of M31 with large reflectors were necessarily made only a few days in each month, and most of the novae were discovered at some unknown interval after maximum. The mean light-curve was constructed on the simple assumption that

maxima occurred midway in the unobserved intervals preceding discoveries. By restricting the data to unobserved intervals less than a month, it was possible to use a large number of novae and derive a mean point on the light-curve at about 15 days after maximum, and a short section of the curve in either direction. The mean maximum was then derived by extrapolating this segment of the light-curve on the assumption of a constant slope (of the order of 0.05 magnitude per day).

Baade, examining the best available photographic light-curves of galactic novae, found that the luminosities faded rapidly during the first few days, then more and more slowly until, by 3 weeks or so after maximum, the slopes were comparable with those observed in M31. He pointed out that the two groups of novae should properly be compared in the most reliable section of the mean light-curves rather than at maximum where the data in the spiral are few and unsatisfactory. If the comparison is made at 20 days, the two curves agree fairly well over a short range, and the extrapolation to maximum luminosity can be made on the basis of the well-determined curve for galactic novae. The procedure leads to a mean maximum in the spiral at $M=-6.7$ to -7, depending on the method of weighting the data, in excellent agreement with current values for galactic novae. Moreover, the brighter novae seem to fade more rapidly than the fainter, and such a correlation would evidently increase the dispersion about the mean maximum suggested by the incomplete data for the spiral.

Thus the outstanding discrepancies are removed. We can state with some confidence that the relative luminosities of novae and Cepheids agree with those known in the galactic system, well within the uncertainties of the observations. Novae in the two systems appear to be strictly comparable, and occasional maxima of $M=-9$ are readily accounted for as random deviations from the statistical mean.

SUPERNOVAE

Another type of nova in M31 is represented by the famous star of 1885, S Andromeda, which reached a maximum of the order of $M=-15$, or twice the total luminosity of the average stellar system. The outburst occurred before the days of the spectrograph, and the many descriptions of the visual observations must be read in the light of information derived from the photographic study of similar stars made during the past year. It now appears that S Andromeda was a typical example of the rare, spectacular supernovae which form a well-defined group of objects quite different from any others known to astronomy. Supernovae represent the sudden release of energy on a tremendous scale, and their unique spectra offer problems whose solution should furnish information of a new kind.

The outbursts occur with a frequency of the general order of one per stellar system per several (possibly four or five) centuries. The frequency in giant nebulae, such as M31 and our own galactic system, is presumably greater than the average, and, consequently, we might expect to find records of several examples scattered through the history of the last 2,000 years. Plausible instances have been assembled (for example, a nova outburst in 1054, whose remnants are probably now observed in the Crab nebula, and Tycho's nova of 1572), but in general it is not possible to establish specific, individual cases.

GLOBULAR CLUSTERS

A large number of objects have been found in M31 which, from their forms, structures, colors, and spectra, have been provisionally identified as globular clusters, although no individual stars can be seen. The 140 known objects form a homogeneous group in which the intrinsic luminosities range from $M=-4.7$ to -7 and thus exhibit a relatively small dispersion around the mean value, which is about -5.3.

That globular clusters in the galactic system also form a homogeneous group is indicated by Shapley's classical investigation of their distances. When his peculiar scale of total luminosities (which he humorously calls convenient rather than conventional) is corrected, the absolute magnitudes range from about -5 to -9, with an exceptional cluster, Omega Centauri at -9.8. The mean value is near -7.3.

Thus the two groups overlap to a considerable extent, but the clusters in the galactic system are systematically brighter than those in the spiral by about two magnitudes. The discrepancy is fully established, and represents an intrinsic difference in the group characteristics. The brightest of the objects in M31 is fainter than the mean of the galactic globular clusters. The discrepancy, however, is not so disturbing as that formerly presumed in the case of the novae, because globular clusters are known in the Magellanic Clouds, and they also appear to be systematically fainter than the galactic objects—comparable, in fact, to the objects in M31. Moreover, similar objects are recognized in several of the nearer nebulae, and the average luminosities vary from system to system. These considerations detract from the value of globular clusters as criteria of distances, but they suggest a new field of investigation, namely, the comparative study of the group characteristics of globular clusters in different environments.

Unlike the clusters in the galactic system, which are believed to exhibit a spherical distribution, those in M31 follow the flattened, lens-shaped distribution of the general luminosity. The novae

114728—39——11

follow the same pattern; they may appear anywhere in the nebula but are most frequent in the bright, unresolved nuclear region. Cepheids, on the contrary, follow the complementary distribution of the supergiants; they favor the spiral arms and tend to avoid the nuclear region.

These notes, which omit many individual features of the triple nebula in Andromeda, and almost the whole of a considerable body of spectrographic data, are yet sufficient for our purpose. The nearest of the neighboring spirals stands forth as a great, independent stellar system, an island universe, separated from our own system by a vast stretch of appreciably empty space. If we were in that nebula, and looked back across that space, the system of the Milky Way presumably would resemble the actual appearance of M31 in its dimensions and in many of its structural features.

As our explorations sweep outward, we recognize countless other members of this same family. They are the true inhabitants of the universe. The nearer systems appear large and bright. Then we find them smaller and fainter in constantly increasing numbers, and we know we are reaching out into space farther and ever farther until, at the extreme limit of our telescopes, we reach the last outposts of the observable region of the universe. With the 100-inch reflector, the great spiral in Andromeda could still be recognized as a nebula if it were so remote that its light had to travel for a thousand million years to make the journey.

OUTER REGION OF THE GREAT SPIRAL IN ANDROMEDA (MESSIER 31).

THE SUN AND THE ATMOSPHERE [1]

By HARLAN T. STETSON
Massachusetts Institute of Technology

[With three plates]

The subject assigned me for this evening is peculiarly gratifying, for there is a new emphasis being placed upon the importance of science to human welfare. Certainly of the cosmic elements necessary for our well-being, no two are more vital to us than the sun's radiation and the atmosphere we breathe.

As we all know, the earth's atmosphere consists of nearly one-quarter oxygen, three-quarters nitrogen, a sprinkling of carbon dioxide, with a bit of seasoning of the noble condiments of argon, neon, crypton, xenon, and a trace of helium. Here at the earth's surface, we can count on a little more than 1 percent of moisture in the form of water vapor to prevent the complete desiccation of academicians and others. For a thorough mixing of these elements of the atmosphere and the maintenance of its temperature as well as the variations of its temperature, we rely upon the sun. Rarely more vividly have we had impressed upon us the relationship of our atmosphere to the sun as a part of our cosmic environment than has been evidenced lately by some magnificent displays of the Northern Lights. Flaming gorgeously red, a hundred or more miles high, like neon signs they advertise the lofty air, swarming with the traffic of electrons, ions, and particles, all jostling one another as they are stimulated by radiations from the sun during a period of great sunspot activity.

If we look at the sun through a telescope, we see a gaseous globe approximately one million times the size of the earth in volume with a hot radiating surface of about 6,000° C. in temperature and frequently, as on the day when this photograph (pl. 1) was taken, besprinkled with dark patches that are called sunspots. From watching the motion of these spots, we learn that the sun rotates about an axis. This rotation is not uniform but is most rapid at the equator where one rotation is completed in about 25 days. Halfway between the equator and the poles, observations indicate 3 extra days are consumed in a single rotation.

[1] The seventh Arthur Lecture, under the auspices of the Smithsonian Institution, February 24, 1938.

We need scarcely remind a Washington audience that through the long painstaking investigations of Dr. Abbot, Secretary of the Smithsonian Institution, the amount of energy that the sun pours forth has been measured with such precision that we not only know the average quantity of heat and light emitted but that this average varies from time to time to the extent of some 2 or 3 percent. Expressed in engineering language, we can say that the earth's share of the sun's output is in the neighborhood of 450 million million horsepower. Because of its relatively insignificant size and because also of the great distance that separates the earth from the sun, a distance of 93 million miles, our planet intercepts but one two-billionth of this total solar output. Even so, if we stop to consider what the cost to the earth would be were we charged for a year's service of heat and light from the Solar Utilities Power and Light Company, we would find our indebtedness mounting to staggering proportions. At a price of 1¾ cents per kilowatt-hour, the annual budget that would have to be allowed for sunshine for the United States alone would aggregate a total of 327 quadrillion dollars.

Of course such large figures as quadrillions are indeed difficult to picture. If we restrict our interest for the moment to the City of New York alone, we find that the cost of sunshine for Greater New York for just one day amounts to 100 million dollars.

Knowing how much of the sun's energy strikes the earth and the small proportional amount which the latter intercepts, one can easily calculate the total output from the Solar Power House. It is 380,000,000,000,000,000,000,000 kilowatts. The solar dynamos are evidently running at full-tilt and giving continuous service.

Life on the earth during the past, present, and future so depends for its well-being upon this constant amount of sunshine that we may well be interested in how long the Solar Power Company can remain solvent and how long it can continue to operate while human beings inhabit the earth. Meanwhile, we are impressed with the apparent waste of the sun's natural resources so far as any use by mankind is concerned. Fortunately for us, millions of years ago sunshine provided the energy for growing the vast tropical forests of the Carboniferous era. It is the carbon in those fallen tree trunks that we are mining today in the form of coal, the chief source of fuel for our own public utilities. Thus nature has stored in those primitive forests buried underground unthinkable calories of canned sunshine that brightens our highways and illuminates our buildings during the long nights when the sun is below the horizon. So the sunshine of the past is being brought literally to light again. Even the ultraviolet light in our health lamps is again directly traceable to the sunshine of those days when the dinosaurs roamed through the vast tropical forests.

If we live where we obtain our electric current from utility companies operating solely by water power, we do not dodge the issue of our debt to the Solar Power Company. The radiation from the sun transforms the water of the oceans, lakes, and streams into the ascending water vapor that condenses into clouds and falls in rain, feeding mountain streams, and rivers that turn the giant turbines of the hydroelectric plants. A fair estimate of the amount of water evaporated and precipitated in rainfall in 1 year is 480 million million tons. To carry on this gigantic irrigation enterprise requires the expenditure of 1,000 million horsepower continuously throughout the year, yet only a very small amount of solar energy is consumed in running this rain-making machinery.

How long the Solar Power Company can continue to operate depends upon its source of supply, and to answer this question we must avail ourselves of the best guesses of science. Dismissing as utterly inadequate earlier hypotheses, our best guess now is that the chief source of energy is within the atoms of which the sun is composed. The two simplest atoms about which we know anything are those of hydrogen and helium. Hydrogen is the highly explosive gas which was the cause of the *Hindenburg* disaster, and helium is the inert nonexplosive gas which those responsible for this giant airliner would have liked to have substituted for hydrogen, could they have obtained it. Four hydrogen atoms constitute the necessary building material for one helium atom with just a bit of energy left over.

It appears probable that within the hot interior of the sun the transmutation of hydrogen into helium is continually taking place, thus releasing an enormous amount of heat from the surplus energy left over from each combination of four hydrogen atoms as they form one helium atom. Every time such a transmutation takes place one percent of the weight of the materials involved is liberated as energy. On such an hypothesis the sun could have well kept up its present state of radiation from as far back in geologic time as we have any reason to consider. Of course the sun is constantly losing weight in the process. The loss of weight has been calculated to be 4,200,000 tons every second, but we scarcely need worry about the fuel supply being exhausted while the sun still has about 2,000,000,000,000,000,000,000,000,000 tons of matter left in it!

Passing over reminders of our indebtedness for the various services the sun renders, we shall come to see that we are quite as much interested in analyzing the kinds of radiation that the sun sends out as we are in the total amount of energy received. When we analyze this radiation we discover that it covers a wide range of frequencies or wave lengths. It seems probable that each of these wave lengths or frequencies renders a special kind of service to the earth and its atmosphere.

We are all familiar with the fact that if sunlight is split into its component colors by means of a spectroscope we can see a large variety of the radiations represented by the various parts or colors of the solar spectrum. The visible range to which the eye responds represents frequencies extending from 400 million million cycles per second to a frequency just about double this, or 800 million million cycles per second. The sensation of the higher of these two frequencies is that of violet light, and the sensation produced by the 400 million million cycle frequency is that of deep red light. In between these two extremes of the spectrum fall the intervening colors. But outside this so-called visible range to which the eye responds there is a vast scale of radiations both beyond the red end of the spectrum which we call the infrared and far down below the violet which we call the ultraviolet.

By means of the photographic plate, we can extend the map of the spectrum in either direction. Far out beyond the red end are heat radiations from the sun that may be measured with the thermopile or the bolometer. It was during the days of Dr. Samuel Pierpont Langley, a predecessor of Dr. Abbot as Secretary of the Smithsonian Institution, that a very complete and careful survey of the radiations from the sun was carried out, extending into the infrared. Today much research is being done in measuring the extremely short waves, or high-frequency radiations out beyond the violet, for the ultraviolet is coming to have increasing importance not only from the point of view of health but from the point of view of the radio engineer.

It is undoubtedly the impact of these very short waves or high-frequency radiations upon the top of the atmosphere that is responsible for its ionization that makes possible all our radio communication. Fortunately for us, most of the ultraviolet light is stopped in the upper atmosphere owing to the presence of a small amount of ozone which acts as an absorbing screen to these high-frequency radiations. If the ozone in the upper air were reduced to standard atmospheric conditions at the earth's surface, it would form a layer scarcely more than 2 millimeters thick. Through the 2-millimeter layer a sufficient amount of ultraviolet still seeps through to the earth's surface to produce the necessary vitamins for our well-being. Were this ozone layer absent, on the other hand, it would be quite impossible for us to survive under the extremely short wave-length radiations that would penetrate to the earth's surface.

Thus, we see it is the combination of both the sun and our atmosphere that makes life on the earth possible. The sun not only radiates health-giving sunshine but it also radiates death-dealing rays. Were it not for the protecting shield of the earth's atmosphere, the sun would be the death of all of us. The atmosphere, then, provides us, on the one hand, with oxygen for maintaining life, and on the other hand, shields us from the highly penetrating rays from the sun that

are dangerous in the extreme. The atmosphere is a sort of buffer state, the very top of which receives a violent bombardment of high frequency radiations from the sun that is prevented from reaching the surface of the earth by the absorbing power of the molecules of gases contained in it. Up where this bombardment occurs, we witness the auroral displays, such as the brilliant occurrences of last January. These displays are in reality electrical discharges in the thin atmosphere occurring at the active front where are received the heavy artillery of corpuscles, electrons, and radiations which fall upon it from space outside and for which the sun appears to be chiefly responsible.

It is this blanket of atmosphere that enables the earth to retain during the night much of the warmth generated by the sunshine falling upon it during the day, thus preventing the temperature of the earth from falling to extremely low temperatures during the hours of darkness.

Though the effective atmosphere is many miles thick, when compared to the size of the earth itself it is but a thin shell, hardly more than the thickness of the paper upon which the map is printed on a desk globe compared to the size of the globe itself.

If we look at a cross-section of the earth's atmosphere, it may for convenience be divided into three zones or layers in which the stratosphere occupies the middle ground. The region below the stratosphere is that which contacts our immediate surroundings and provides the winds and atmospheric currents, giving rise to all our weather. We call this lower region comprising perhaps the first 5 or 6 miles the troposphere. The region above the stratosphere is the ionosphere. If we send a recording thermometer aloft, we find that while passing through the troposphere the temperature steadily falls until a height of 10 or 12 kilometers is reached, when the temperature reaches the extremely low value of $-55°$ C., or some 68° below zero Fahrenheit. Strangely enough, for the next 30 miles or so there appears to be little change in temperature. This is the region of the stratosphere. The weather forecaster for the stratosphere would have a relatively simple task, for day after day, year in and year out, his prognostications would be "clear and cool," and his forecasts would be 100 percent correct. At a height of 60 kilometers or some 40 miles, the temperature would begin to rise again. Recent investigations give some evidence that at extreme heights, up where the auroral fires play, temperatures of 1,000° C. have to be postulated to account for the presence of the oxygen that is there. The extremely rarefied condition of this upper atmosphere, however, calls for perhaps a quite different interpretation of temperature than that to which we are ordinarily accustomed when determining temperatures by the thermometer at the earth's surface.

Ascending through the cross-sections of the atmosphere, we find there is a rapid decrease in the amount of atmospheric pressure. Within the first 3 miles from the earth's surface, half the total amount of oxygen and nitrogen, the principal atmospheric ingredients, are included. The limiting height to which the thinning atmosphere extends is somewhat difficult to fix. Perhaps we should place it at 400 or 500 miles, although recently Dr. Carl Störmer has observed auroral streamers reaching to heights of 600 miles or more. Where auroral streamers go, some of the thin atmosphere must extend.

Through the courtesy of the Smithsonian Institution we have provided for us here [2] a piece of apparatus from which the air can be exhausted so that we can gradually simulate conditions that would be encountered were we to board an imaginary balloon and ascend upward. To apply such electric potentials as appear to exist aloft, there are two electrodes entering this glass tube at either end and a high voltage is applied across these terminals. Under the standard atmospheric conditions of this room which is now the condition inside the tube, you see there is no evidence of a passage of electricity. Air under ordinary conditions is a relatively good nonconductor. If, however, I now start the vacuum pump going and begin to exhaust the air from this closed tube, the pressure will be gradually reduced and we shall soon see the beginning of an illumination as an electric current passes through the rarefied air from one end of the tube to the other. The color already simulates the red tints of the aurorae. As the vacuum in this tube increases, we imagine ourselves rising higher and higher through the stratosphere. We note the changing form of the electrical discharge and the pale blue color that now occurs as the ionization of the thinning air in the tube becomes more complete. The glow is dimming now as we are attaining the equivalent altitude of some 400 or 500 miles. At this imaginary height the air molecules are becoming scarce. The artificial auroral glow is dimming. Now it has ceased altogether for the vacuum obtained is too nearly complete for current to pass longer. We are at the very top. Now shutting off the pump we will throw a little valve here, and gradually admit the air from the room again. In our imaginary flight our gallant gondola is now descending. Watch for the first appearances of the auroral glow. There it is—first pale blue, gradually increasing in intensity as we rapidly descend to greater densities of the air. Once again we see the pink striations. We are coming rapidly into the stratosphere. Now come the irregular discharges characteristic of the denser regions. The glow dims and disappears once more. We have fallen rapidly down to full atmospheric pressure again where the air becomes nonconducting and the discharge has ceased.

[2] Experiment shown to the lecture audience.

This is an illustration of the way in which aurorae are formed in the upper atmosphere of the earth under the electrical excitation that appears to be caused by the sun's radiation as molecules of oxygen and nitrogen are ionized in the regions where the pressure is very low.

If we make a chart of the numbers and occurrences of these aurorae we find there seems to be a curious connection between the frequency and brightness of auroral displays and the state of the sun as marked by the appearance of sunspots. Professor Brooks, Director of the Blue Hill Observatory, has kindly allowed me access to the records made of aurorae at that station for the last 30 years. Utilizing the observations of the brighter aurorae, we have here a graph showing the variations in auroral frequencies occurring in years distributed with respect to the maximum occurrences of sunspots. The fewest

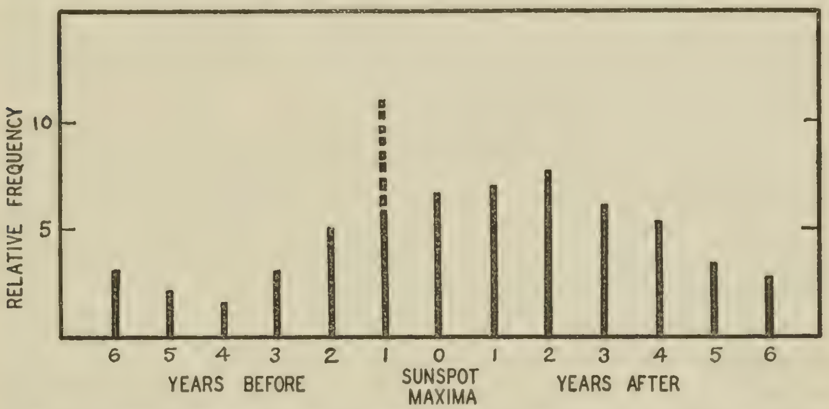


FIGURE 1.—Relative frequency of auroral display at Blue Hill Observatory from records 1885-1937.

number of aurorae appear to occur from 4 to 6 years before or after the years marking sunspot maxima. The time when aurorae appear most frequently would seem to be about 2 years after the passing of the maximum of sunspots. The very high column occurring 1 year before sunspot maximum is due largely to an unusually large number of observations in 1893. These results corroborate rather well those of a longer series of observations tabulated by Dr. Chree extending for over 100 years, or from 1750 to 1877.

The fact that aurorae therefore appear to occur with greater frequency at the times when sunspots are most numerous suggests an electrical effect in the upper atmosphere for which sunspots may be responsible. Much of our present knowledge of aurorae is due to the exhaustive studies and mathematical calculations of Dr. Störmer of Blindern, Norway. By careful analysis of the motion of charged particles in the magnetic field of the earth he has been able to deduce tracks of ionization so simulating auroral forms as to indicate very

significantly that such discharges in the upper atmosphere are indeed the result of bombardments of electrons coming in from outside, warped by the magnetic field of the earth. In endeavoring to express such phenomena on an electronic hypothesis we may well look at the sun, therefore, for a consideration of the character of sunspots and to trace any possible mechanism by which corpuscular charges might be ejected in the regions of the sunspots themselves.

When we look at an enlarged view of a sunspot and analyze the light from it we find that the dark interior center is surrounded by a turbulent area. A photograph taken in the light emitted by hydrogen at one particular frequency reveals that here are whirling masses of gas, arranging themselves in veritable vortices. There is every indication, then, that a sunspot is in reality a terrific solar hurricane. It was in 1908 that the late Dr. George Ellery Hale, the founder and director of the Mount Wilson Observatory, first observed that sunspots were giant cyclones in the sun's atmosphere. They are indeed very similar in their formation to the tropical hurricanes that originate in the West Indies and sweep northward.

An ordinary telescope would never have disclosed all this about sunspots. With a special contrivance of his own invention called the spectroheliograph he was able to photograph the sun, utilizing the light of a given frequency from one chemical element at a time. The spectroheliograph is a sort of a combination of a spectroscope and a moving plate arrangement, somewhat similar to a motion picture outfit in its operation. With this device it is possible to photograph the distribution of clouds of chemicals whose presence in the sun's atmosphere is betrayed by the lines in the spectrum. Since the invention of the spectroscope it has been known that hydrogen and calcium, for example, are very conspicuous elements entering into the sun's makeup.

With photographic emulsions made especially sensitive to the red light emitted by hydrogen Dr. Hale photographed on a moving film the entire solar surface so far as it was covered by bright luminous hydrogen clouds. The resulting representations of the sun appeared very different from photographs made in ordinary light. Not only were large clouds of hydrogen gas discernible all over the sun, but in the neighborhood of sunspots they seemed to be swept into the heart of the spot as though they were caught in the center of a whirlpool. Pictures of sunspots taken in this way show the same kind of vortex as one often sees when a basin is being emptied of water by the sudden removal of a drain plug at the bottom of the bowl. Such an appearance might be presented by the top of a terrestrial cyclone or tornado if photographed from a stratospheric balloon. The dark center of the spot forms the center of the vortex; the outlying shaded region that characterizes the so-called penumbra of the sunspot would represent

the turbulence bordering upon the central funnel about which the atmospheric particles are rapidly rotating. Thus we see there is a close analogy between the meteorology of tropical cyclones and that of sunspots. To carry the analogy still further, spots north of the sun's equator are in general whirling in one direction while corresponding spots south of the equator whirl in the opposite direction. If the rotation of the one is clockwise, that of the other is counterclockwise. This again is characteristic of the differences of rotation of tropical hurricanes on the earth originating in the northern and southern hemispheres, respectively.

Had it not been for the trick of splitting up sunlight into isolated frequencies by means of the spectroscope, we should never have had pictures showing the existence of solar vortices such as we have today. In the ordinary photograph of the sun, the light emitted by every chemical element in the sun's atmosphere is clamoring to tell its story. The result is revealed in a rather jumbled picture of what is happening on the sun. The spots show up as dark regions only when the light-emitting power of every element of the sun is damaged in the vicinity of these violently disturbed regions.

The spectroscope is very much like a highly selective radio receiving set. The sun is a high-powered station sending out light, broadcast in all the wave lengths and frequencies. When we look at the sun or photograph it with a telescope alone, we are using all of the light and are, so to speak, operating a radio receiver which admits all frequencies at once. Thus we get a composite but very jumbled picture of what is happening on the sun's surface so far as details are concerned. By means of the spectroscope, however, the photographic apparatus, to continue our analogy, may be tuned to a single frequency such as the 470 million megacycle frequency that the red line of hydrogen emits. Tuned to this frequency, the spectroscope stills the tumult of all other elements and lets hydrogen tell its own story. It is then that we obtain the clear photographs conveying so beautifully the detailed information about the vortical whirls around the solar storm centers that would otherwise be lost in the jumble of too many story-tellers.

At about the same time another brilliant discovery due to Dr. Hale came from the Mount Wilson Observatory. It had long been known that the frequencies of light waves were distorted if there were a powerful magnetic field at the light source. This had been demonstrated in the laboratory shortly after the reason for such a phenomenon had been given by Zeeman in 1894. When the Mount Wilson observers examined and actually measured the frequency of light coming from the centers of sunspots, it was found to have changed frequency in exactly the way that light waves are distorted in the laboratory when a powerful electromagnet is placed around the source of light

being examined. If additional proof were needed for the explanation of the changed frequencies, it may be stated that the double and triple lines found in the spectrum of sunspots indicated that the light was polarized just as in the case of the polarized light waves coming from the laboratory source upon which the magnetic field is impressed. Thus came the startling revelation that sunspots were not only terrific hurricanes but every center was in itself a powerful magnet. Since a magnetic field may exert a repulsing effect upon swiftly moving electrons, we see some reason that charged electric particles can be actually hurled from sunspot centers at velocities which may carry them through space into the earth's atmosphere, thus ionizing the upper regions of the air in a way that would produce auroral displays. In the light of such a mechanism, therefore, we see a possible reason why aurorae occur in greater numbers and at greater brilliance at times when these solar storms occur most frequently.

Curiously enough, for nearly 300 years it has been known that the direction of the compass needle and the intensity of the earth's magnetic field appear also to be affected by sunspots, for in the year when

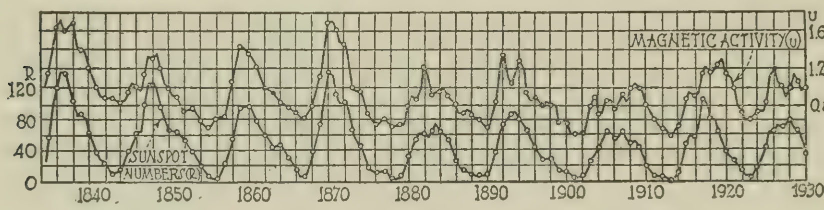


FIGURE 2.—Sunspots and variations in earth's magnetism fluctuate together through the years.

sunspots are most numerous, magnetic disturbances are most frequent and appear with marked intensity.

If we examine a graph representing the sunspot numbers for the last 100 years, we become aware of the close parallelism between these magnetic variations on the earth and the variations in the numbers of sunspots. Furthermore, it will be evident that the years when sunspots are most numerous follow with more or less regularity an interval of somewhat over a decade between the times of maximum sunspot activity. This solar cycle, or sunspot period as we sometimes call it, is usually conceded to be on the average of about 11.3 years duration. But an examination of the graph will show that sometimes the interval between maxima is as little as 9 years and on one occasion was as great as 17 years. We appear now to be in the midst of the period of maximum activity of the present cycle.

The source and nature of the earth's magnetism is still one of the great mysteries of science. Although the close parallelism between magnetic changes on the earth and the appearance and disappearance of sunspots has been recognized for many years, it was not until the

discovery of the magnetic character of sunspots themselves by Dr. Hale and the more recent discovery of an ionized region in the upper atmosphere of the earth that any real explanation appeared as to why sunspots and changes in the earth's magnetic field should show so close a parallelism.

Everyone knows in a general way that the earth is a magnetic sphere. That the compass needle does not point true north except in various restricted parts of the globe is also a fact which is generally recognized. Perhaps comparatively few people realize, however, that the compass needle is constantly wandering back and forth every day by a slight amount. When the sun rises in the east, the north end of the compass needle turns slightly toward that direction. By noon when the sun is south, it is pointed in its normal position. Then in the afternoon as the sun wanders and sets in the west, the compass needle wanders likewise to the west, coming back again to its normal position about midnight when the sun is below the northern horizon. This goes on day after day, month after month—but during the years when sunspots are most numerous these daily excursions of the compass needle will on the average be twice as great as during the years when sunspots are lacking. These diurnal wanderings of the compass needle can now be roughly explained as due to the effects of ionization of the upper atmosphere by sunlight. As the electric charges become separated in the process of ionization of the molecules of nitrogen and oxygen under the bombardment of ultraviolet light from the sun, the movements of these ions create a perceptible current, deflecting the compass needle from its normal magnetic position. We may infer, therefore, that at times of sunspot maxima the number of these ions in the upper air is materially increased, producing a more marked magnetic effect. The strength of the magnetic field of the earth, therefore, may be considered as increasing and decreasing with the variation in the intensity of the ionization of the upper air that changes with sunspot occurrences. Most of our knowledge of the ionized region has come about through the invention of radio.

In the early days of wireless, it was thought that electric waves which carried telegraph messages without wires traveled in straight lines over the earth, just as light waves do. With this conception one could never hope to communicate over very great distances, since the curvature of the earth would prevent the passage of the waves as the earth's huge hulk bulged into the communication path. The earlier wireless engineers thought that only by building higher and higher antenna towers could one ultimately hope to communicate over the thousands of miles that would make transoceanic wireless possible.

How amusing such a picture appears when today any one of us can turn the knob on our short-wave sets and bring in broadcasts from London, Rome, or Berlin. Of course, these early crude notions about

the way in which electric waves travel were erroneous. Such, nevertheless, is the way in which science has groped into the unknown. Somebody experimenting with wireless and listening in found himself quite unconsciously eavesdropping on Marconi waves from far-away Europe. Instantly the thought about how wireless waves travel had to be changed. Evidently the ether waves followed the curvature of the earth and did not travel in straight lines after all. This led Professor Kennelly of Harvard to postulate that there must exist high above the earth's surface, perhaps 100 miles or so up, an electrified conducting layer from which the electromagnetic waves emitted from the powerful antennae were reflected back to earth. The earth's upper atmosphere, therefore, in his mind formed a conducting layer and imprisoned the radio waves between the earth's surface and space outside. A few months after Professor Kennelly published his idea, the English scientist, Oliver Heaviside, announced a similar conclusion quite independently. In honor of these two distinguished men this upper region of the earth's atmosphere that is electrically ionized is commonly referred to as the Kennelly-Heaviside layer, also designated as the E layer.

If we look at a diagram (pl. 2) which presents a vertical section of the earth and its atmosphere, we see that this Kennelly-Heaviside layer exists at an altitude of from 80–100 kilometers. Radio waves emitted from a sending station in all directions arriving in this ionized region have their velocity and direction changed as they penetrate further and further into the region, until at length they are bent back to earth again, reaching receiving stations hundreds and sometimes thousands of miles from the source whence they were broadcast. This region lies far above the stratosphere and generally above the region that is usually regarded as that where ozone is manufactured. This E layer is particularly favorable for reflecting or turning back radio waves of the frequencies which are most generally used for commercial broadcasting in connection with our entertainment programs. Radio waves of much shorter wave lengths or of higher frequencies penetrate and actually traverse through this region until they reach what appears to be another ionized region called the F layer originally postulated by Professor Appleton of England. This F layer lies some 200 kilometers high or in the territory where auroral streamers stage their gorgeous displays. If the ionization of these upper regions is more intense as we near the period of maximum sunspot activity, one might well expect that some change might be observed in connection with radio transmission.

Anticipating a new field of research, a Boston radio engineer, Mr. G. W. Pickard, and myself became interested in the making of quantitative measurements of radio reception during the last sunspot maximum of 1928 in an endeavor to discover if such anticipated effects

on radio communication could be measured. After a few years' observations, it appeared to be evident that when solar activity decreased, the field strength of a Chicago broadcasting station observed in Boston notably weakened, whereas as sunspots became less numerous there was a marked increase in the intensity of the radio waves from Chicago. A similar investigation carried on during the decline of sunspots from 1930 to 1932 between Chicago and the Perkins Observatory of Delaware, Ohio, yielded data to indicate that with a decrease of sunspots from a monthly average of 60 at the beginning of 1930 to a monthly average of about 10 in 1932, radio reception increased six-fold in its intensity.

Let me hasten to point out that this does not necessarily imply a 600 percent decrease in the ionization of the Kennelly-Heaviside layer over this interval, for it appears probable that a much smaller change in the percentage of ionization could so appreciably alter the degree of the angle of reflection at the ionized layer as to increase materially

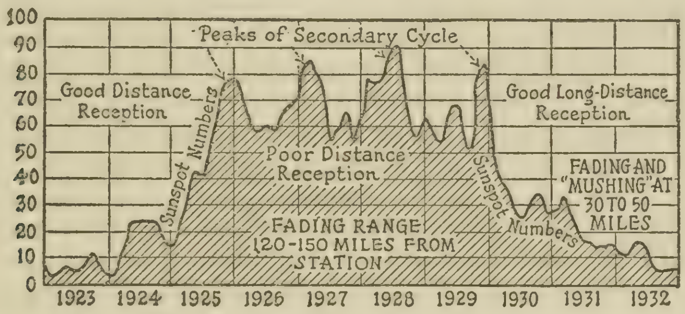


FIGURE 3.—Solar activity serves as a basis for predicting quality of radio reception for broadcast frequencies. The vertical scale represents sunspot numbers.

the strength of a wave of a fixed frequency over a fixed path as received at any given point.

Let us take an illustration from the sporting world. Suppose we were in a squash court and attempted to place a tennis ball at a predetermined spot on the court by a serve directed to the ceiling. If we judiciously direct our serve, we may land the ball at its desired destination by a reflection from the ceiling of the court. If now, the ceiling should be raised or lowered by even a relatively small amount, the same stroke would result in landing the ball far from its mark. Following this analogy, a radio receiver may be at an optimum position for receiving a broadcast wave reflected from the ionized layer. Let the ceiling of reflection of this wave be altered either in height or in its ionic content, thereby increasing or decreasing the ionization present, and the wave may arrive at the earth so far from our receiver that we get notably bad reception. The radio, therefore, becomes a sensitive and extremely useful tool in recording changes of degree of ionization

in the Kennelly layer. When we observe field strengths at long distances, we are in a way tracing the integration of the effect throughout the whole transmission path.

Another way in which we gain important information as to the sun's effect upon the upper atmosphere is by making radio soundings from day to day. This method which has been in use for some years at the National Bureau of Standards, at the Department of Terrestrial Magnetism of the Carnegie Institution in Washington and elsewhere, consists of sending up a radio pulse, letting it bounce off the reflecting layer, come back nearly vertically into a sensitive receiver, and measuring the time elapsed while the wave was traveling this path to the ionosphere and back. Assuming that the radio wave travels with the velocity of light, one can calculate from the elapsed time the height to which the pulse ascended before it was turned back by the ionosphere. The method, you see, is very similar to that used at sea when a sound wave is sent from an oscillator in the ship's hull to the ocean bottom and is received back at the microphones of the ship's navigating equipment. Knowing the speed with which sound travels through water, the ship's captain can thus determine the ocean depth. Soundings made in the ionosphere, therefore, reveal different conditions at various times, showing marked changes in the ionic density dependent upon the hour of the day and the season of the year. This method of radio soundings is sometimes modified by changing the frequency at which the radio pulse is emitted. If the frequency is sufficiently increased, these more penetrating waves may pass completely through the ionized layer and not return. When such a frequency is attained, it is known as the critical frequency. Its value is an important index for studying cosmic effects.

During the last few years of sunspot activity, there have been occasions when remarkable fadeouts have occurred in radio communication. In several of these instances extraordinary explosions have occurred on the sun simultaneously with the interruption of all radio communication in general. A record has been kept by Dr. Dellinger, at the National Bureau of Standards, of such radio fadeouts as are reported. In many of these instances observations at the Mount Wilson Observatory have shown violent solar eruptions taking place simultaneously. It would appear that the intense ionizing radiation from the region of the sun where these eruptions occur reaches the earth with the velocity of light and of sufficient intensity to disturb immediately the ionized layer, confusing the reflection of radio waves, and thereby resulting in these fadeouts which sometimes last for an hour or more. Records at magnetic observatories show that during such instances characteristics of the earth's magnetic field are likewise suddenly altered.

Could we visualize the ethereal substance of the ionosphere as we visualize the surface of the ocean, we should find times when terrific storms were raging in this ionosphere. Here ions and electrons are being hurled hither and yon as though some great electrical wind played upon its surface, creating waves literally miles high. Frequently the turbulence attains such proportions that no reflecting surface for radio communication seems possible at all. When disturbances on the sun subside, the undulations in the ionosphere may quiet down and there is a return to more normal conditions for communication traffic through this ocean of the upper air.

While knowledge of the sun has helped us to understand the vagaries of radio, we are coming to see that radio is one of the most important tools for learning about what happens on the sun and how disturbances there affect the ions in this upper air. Perhaps some day, even though the sky is cloudy, we shall have a sufficient number of reports of radio conditions over the globe so that we can form a very good idea as to what is happening on the surface of the sun by the way in which world-wide radio communication behaves. Unlike the telescope, radio apparatus does not go out of commission when the sky is overcast, for electric waves, of course, pass through the clouds as easily as ordinary daylight comes through window glass.

Concerning the exact method or methods by means of which the sun produces all these electric disturbances of the upper air with the concomitant magnetic variations in the earth, we still lack a great deal of knowledge. The fact that the ultraviolet radiation from the sun is the major factor in producing this ionization appears a reasonable assumption. Whether or not in addition to the effect of the ultraviolet light, streams of charged particles also emanate from the sun in the regions of sunspots is perhaps still debatable. The elaborate mathematical work of Dr. Störmer, in calculating the movements of hypothetical charged particles from the sun striking the upper atmosphere of the earth and thereby producing aurorae, would certainly seem to favor the idea that corpuscular radiation of some sort is responsible for this phenomenon.

One experimental way by which we might determine the relative importance of ultraviolet light and corpuscular radiation from the sun, if such exists, is to observe the radio effects during the phenomenon of a total eclipse of the sun. Measurements of the Heaviside layer heights during the eclipse of 1932 revealed a marked change in the ionization coincident with the arrival of the moon's shadow. As the moon passed off the sun and the normal daylight was restored, the apparent height of the ionized layer again resumed its normal value through the day.

114728—39——12

Chapman has shown that if there is a corpuscular emanation from the sun affecting the ionosphere and if these corpuscles travel, as would be surmised, at velocities much slower than those of light, the effect of the moon in screening off from the earth such a stream of charged particles should cause disturbances in the ionosphere as much as 2 hours in advance of the optical shadow. Such an effect was looked for in the case of the New England eclipse of 1932 but with results that

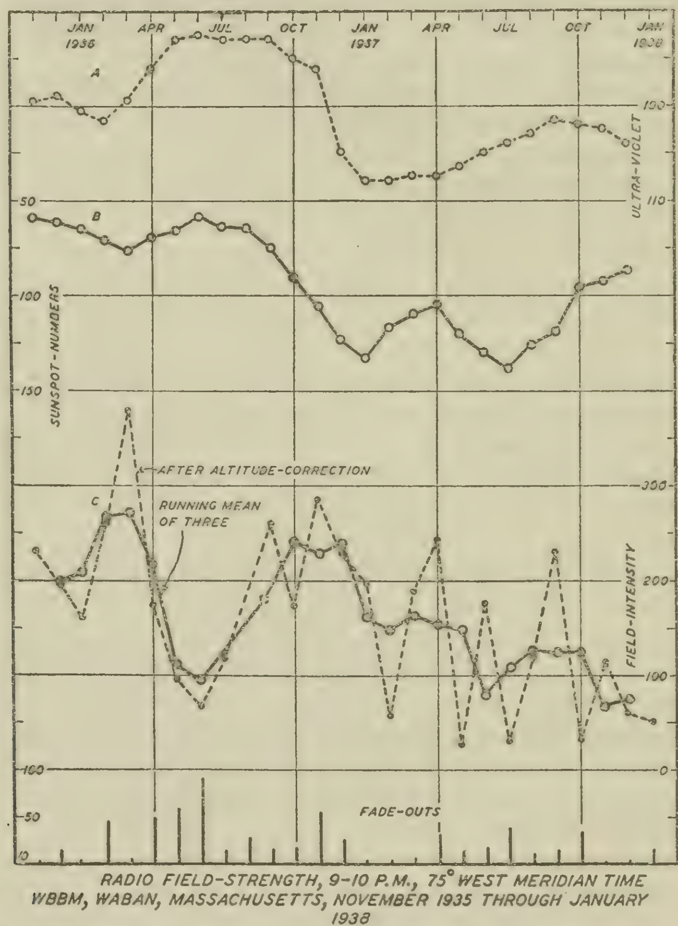


FIGURE 4.—Field strengths of broadcasting station show a decrease trend with increasing sunspots. Curves of sunspot activity and ultraviolet light are inverted in plotting.

were far from convincing. Observations at other eclipses have unmistakably confirmed the hypothesis of ultraviolet light as a source of ionization but only conflicting reports are available for any substantiation of a corpuscular or electronic shadow. One difficulty, perhaps, in detecting the effects of a stream of charged particles or electrons emanating from the sun or sunspots lies in the fact that the paths of

the charged particles would vary very materially from a straight line as they are distorted, both by any magnetic field which the sun may possess and by the magnetic field of the earth when the corpuscles or electrons arrive in the neighborhood of our planet. We should, therefore, preserve an open mind relative to any corpuscular theory, for negative evidence is never completely convincing.

It seems hardly necessary to emphasize the desirability of continuing measurements of radiation from the sun such as have been continued for so many years by the Smithsonian Institution. In connection with measuring the total amount of the sun's radiation it appears especially important that systematic measurements of the ultraviolet in sunshine should form an important part in gaining information as to the interrelation of the sun and the earth. Daily measurements of the strength of the ultraviolet in sunshine made by Pettit at the Mount Wilson Observatory over many years appear to indicate that in general ultraviolet radiation is more intense near sunspot maxima than at sunspot minima. There are, however, many disconcerting discrepancies. A remarkable drop in the ultraviolet radiation from the sun, for example, occurred in the early part of 1936 while solar activity was still rising. It must be remarked that ultraviolet is probably the source of the creation of ozone in the upper air, and at the same time any increase in the ozone content naturally screens from the earth's surface the greater part of this ultraviolet radiation which produces it. Since ozone, therefore, absorbs the greater part of the sun's ultraviolet radiation, it would appear that with any sudden increase in the ultraviolet there would be a concomitant increase in the amount of ozone which, in turn, would effectively reduce the quantity of the ultraviolet light which we would measure at the earth's surface. This seriously complicates the problem, and may account for the fact that a smaller value of the ultraviolet radiation would actually be recorded by our instruments even though its emission from the sun at the same time might be enhanced. Similarly, a sudden dissociation of ozone due to a decrease in the amount of ultraviolet emitted from the sun might well result in a sufficient thinning of the ozone layer to allow apparently a material increase in the amount of ultraviolet coming through the atmosphere to the earth. Our instruments, therefore, would indicate more ultraviolet at a time when the sun might actually be emitting less.

When we take averages of ultraviolet radiation over the years and compare them with solar activity, the correspondence between sunspots and ultraviolet radiation is much more striking than any day-to-day or week-to-week correspondence can exhibit. It would appear feasible and highly desirable that observations of ultraviolet should be made from the stratosphere, utilizing balloons for carrying the recorders aloft. We find that the Smithsonian Institution already

has plans for carrying out such a program of observations daily as soon as funds may become available for the purpose.

With 95 percent of the earth's atmosphere below the apparatus, better measurements of the ultraviolet light could be made than at any station on the earth's surface. Notable advances in the design of apparatus for measuring the ultraviolet part of the solar spectrum have recently been made by Dr. O'Brien of the University of Rochester. Such apparatus yields photographic records by means of which a quantitative estimate of the ozone content of the upper air can be made daily with a high order of accuracy. The part which this ozone plays in modifying the amount and character of sunshine at the earth's surface is of very great importance. For weather and biological behavior are undoubtedly sooner or later dependent upon both the quantity of ozone and the quality of solar radiation received near the surface of the earth.

The idea that weather may be associated with changes in the sunspot cycle is not new. Many investigators have attempted to find relationships between sunspots and weather changes with the ultimate hope that since we can predict with reasonable accuracy the main trends in the solar cycle we may ultimately be able to predict likewise the main trends in changes of weather. The relationship between weather and sunspots is not a simple one. While some may doubt that any direct relationship holds at all, we might say frankly that there is certainly no adequate proof to the contrary.

In spite of many conflicting results, it appears that in general the temperature of the world at large is somewhat higher at sunspot minima than at sunspot maxima. This seems at first paradoxical since we might well expect that at sunspot maxima the sun would send us more heat and radiation than at sunspot minima. Many of Dr. Abbot's observations, especially during the earlier years, seem to corroborate this. Yet the surface temperature of the globe could be actually cooler in years when the earth is receiving more heat from the sun, for increased heat produces increased evaporation which in turn generally results in increased rainfall. Increased rainfall actually lowers the temperature of the earth's surface and again by evaporation, continues to cool the air immediately above. Furthermore, with the warming of the earth, a vast convectional system of atmospheric currents results. As air warmed near the surface of the earth rises, cold air flows in from the polar regions with its chilling effects. It appears entirely possible that even with an increase in the heat received by the earth from the sun, so far as surface conditions are concerned, actually lower temperatures would occur at selected regions.

One thing is certain, and that is that all the weather on the earth is produced ultimately by the sun. So far as changes in the sun's radiation affecting the general circulation of the atmosphere are con-

cerned, it is to be expected that such changes would ultimately give rise to the formation of storms and the storm tracks resulting. One of the difficulties in establishing any intimate connection between weather and sunspots is that our observations of weather tend to be very local.

If one averages weather conditions over the entire globe, as, for example, comparing the average rainfall record at observing stations throughout the world, one might expect at first thought to find some relation with sunspots, assuming that sunspots have anything to do with weather phenomena. Such, however, is far from the case. A storm in one region of the globe means clear weather elsewhere, for a region of low pressure presupposes a region of high pressure adjacent. Similarly, excessive rainfall in a given locality in a given year will usually be offset by one of extreme dryness occurring elsewhere. To

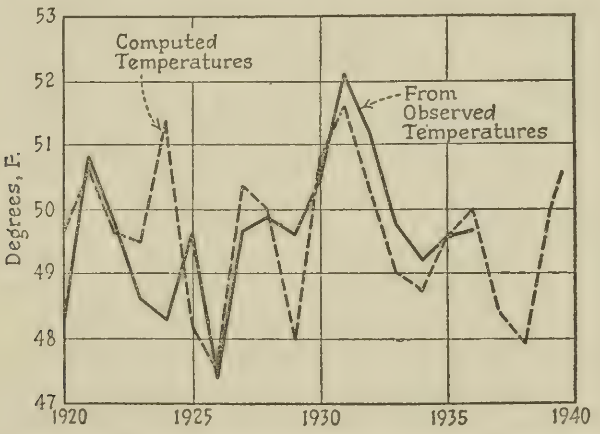


FIGURE 5.—Clayton's prediction of temperatures at New Haven, Conn., based on 68-year period.

average together such effects will obviously lead to no definite conclusion. Furthermore, since storms travel over more or less defined tracks, the migration of these storm centers makes it impossible to get significant results from hundreds of stations scattered from the polar regions to the Equator. If progress is to be made, it will come through a consciousness of the distribution of weather as a whole over the entire globe. For a more accurate picture of world weather, indications for weather in a given locality at a given time may be more easily estimated.

Mr. H. H. Clayton, of Canton, Mass., a well-known scientist who has spent many long years in weather bureau service, is a firm believer that changes in the sun are accompanied by fundamental changes in the earth's atmosphere. He appears to have found very definite indications that changes in the earth's atmosphere in different parts of the world accompany the changes in solar activity attendant upon the solar cycle, in which we can be sure Dr. Abbot would concur.

Looking at the weather on a world-wide scale, Clayton has found that pressures oscillate from one region to another in some way which appears to depend upon the intensity of solar activity. He finds there is an opposite trend over the continents and oceans in summer as compared with winter, and that the trend is different in the equatorial regions from that in the extratropical belts. In the equatorial regions temperatures are distinctly lower at sunspot maximum and higher at sunspot minimum. The same is true in the North and South Temperate Zones, but in the arid regions bordering the Tropics the temperature actually averages little higher around sunspot maximum than at sunspot minimum. From his studies he concludes that while the North Atlantic shows 10 to 20 percent more precipitation, the eastern half of the United States is in the region where rainfall is actually less during maximum activity on the sun. He concludes that our weather is the result of certain progressive wavelike movements of certain disturbed areas, originating in different parts of the world. With each cycle of change in solar activity, the centers of high barometric pressure move from high latitudes to low latitudes and back again. The amplitude of their oscillations and the speed with which these waves progress appears to be inversely proportional to the length of the period of oscillation.

In years of unusually high sunspot maxima as is the case at the present time, areas of high pressure appear to be pushed farther northward. The return of these highs to low latitudes with accompanying colder and clearer weather may, he believes, be so retarded under such instances as to invert the phase of a cycle which has persisted for some time, when the amplitudes of these oscillations have been of less magnitude. Thus there will be several years when the differences in barometric pressure between the equatorial region and North Temperate Zone become greater than normal, and then this period will be followed by several years when the pressure differences become less than normal. The shifting of these centers of action, he believes, is definitely associated with sunspots.

Mr. Clayton's conclusions are based on so large an amount of data and upon such a wide experience in meteorology that no one interested in weather or weather prediction can overlook the significance of these contributions. One might venture to suggest that one of the most important discoveries in the matter of weather prediction may come as a byproduct of some of these investigations.

Various attempts have been made to attribute climatic cycles to changes in solar activity. Perhaps the most outstanding scientific contribution in this direction has come from Prof. A. E. Douglass, of the University of Arizona, who has spent a lifetime measuring variations in the tree growth, especially in the forests of the Southwest and in California. Douglass noted that sequences in periods of rapid

growth of trees, as measured by the widths of their rings, follow very closely the sequences in the sunspot cycle. Since variations in tree growth suggest variations in precipitation, he has accumulated a vast amount of evidence for alternations of wet and dry periods variable with the sunspot cycle, carrying records backward for some 3,000 years. His studies appear to indicate that at least for selected regions, trees have shown most growth when sunspots were most numerous. It does not appear improbable, however, that the growth of trees integrates all favorable conditions and that temperature, the quality of sunlight, and particularly the percentage of ultraviolet enter into the growth rate of trees as well as does rainfall.

Sunspot periods have also been traced with minor discrepancies in the flow of rivers and the level of lakes, some regions responding much more clearly than others to the sunspot cycle.

Altogether we see there are many indications that the earth responds to the changing state of the sun over an interval of a little over 11 years and often by double this period or approximately 23 years. Whether all of the effects produced in the earth and its atmosphere that are noticed at sunspot maxima are the result of the sunspots themselves or whether the state of the sun and its whole surroundings are so activated as to change materially the cosmic environment of the earth is a question still unanswered. Enough has been said to indicate that it is eminently desirable to be able to predict sunspots with all the accuracy that our somewhat scanty knowledge will permit.

Many attempts have been made to analyze the curve of sunspot activity from the time of reliable records, which began in the middle of the eighteenth century, up to the present time. Investigators differ as to the number of significant periods which may enter into the solar graph. In addition to the 11- and 23-year cycles, others of 37, 68, 77, 83, 252, 300, and even possibly as long as 1,400 years have been assigned. Authorities are not in agreement as to the reality of some of these intervals. Obviously we have hardly enough sunspot records to be sure of any intervals of 100 years or more.

Somewhat over 2 years ago, on the basis of the occurrences of the past cycles and the present rate in the rise in sunspots, I ventured to predict that the next sunspot maximum would occur in the early part of 1938, or more than a year before what would have been expected by adding 11 years to the time of the last maximum. If subsequent observations should prove my predictions correct, it would be one of the pleasantest and most unexpected turns of fate for which a scientist could hope. We have not yet an adequate basis for any degree of precision in the sunspot prediction.

The sunspot records obtained during the last year already have outtopped the records of 1917 and indeed all previous maxima subsequent to that of 1870. It will be observed from the sunspot curve that in

general alternate peaks are much more sharp in their formation than the intervening ones. The long drawn-out maximum of 1927–29 should, therefore, be followed by a relatively sharp peak. With the rapid rise upward during the last year and the high maximum of last July, my own view is that the present maximum cannot carry beyond 1938 without a substantial trend downward in the average sunspot numbers.

Mr. Clayton's analysis of the sunspot cycle from 1750–1910 has led him to attempt a prediction from 1910 to 1955, using only the data accumulated previous to his predicted curve. The rather remarkable correspondence between his predicted curve and the observed curve from 1910 to date suggests that his independent forecast for a maximum at the end of 1937 or the beginning of 1938 lends an increased interest to the critical part of the curve in which we find ourselves at present.

There is another important variation in the characteristic of sunspots of which we must not lose sight. This is the apparent drift in the positions of the spots toward the solar equator as the cycle progresses. At the beginning of the sunspot cycle the spots first appear in the neighborhood of 35° either side of the sun's equator. This was exemplified in the case of the present sunspot cycle which started in 1934 with high latitude spots. As the solar cycle advances, the spots increase in number and tend to break out at progressively lower latitudes on the sun. While there is some fluctuation back and forth in latitude from day to day and month to month, the trend is always toward the equator. As the sunspot period approaches the maximum, the average latitude for the maximum number of spots is in the vicinity of 15° both for the northern and the southern hemispheres. After the maximum the spots decrease in size and number but they continue to break out at decreasing latitudes. The end of the cycle is marked by infrequent spots occurring when they are seen on either side of the sun's equator in latitudes ranging from 2° to 5°. By the time this state is reached the next cycle has begun again with spots breaking out once more in high latitudes.

This peculiar trend of latitude during the sunspot period is so far without any adequate explanation. Observation of latitudes, however, helps very much in diagnosing where we may be with respect to the sunspot cycle at the present time. The average latitude of the spots of both hemispheres during the last 3 months has been 15.5° and leads us to believe, therefore, that we are now very close to the present sunspot maximum. By the end of 1938 it would appear that we will find solar activity definitely on the down grade, in which case the next sunspot minimum should arrive not far from 1944.

If we knew what was the cause of sunspots, it would help very much in solving the mystery of the solar cycle and in predicting the future

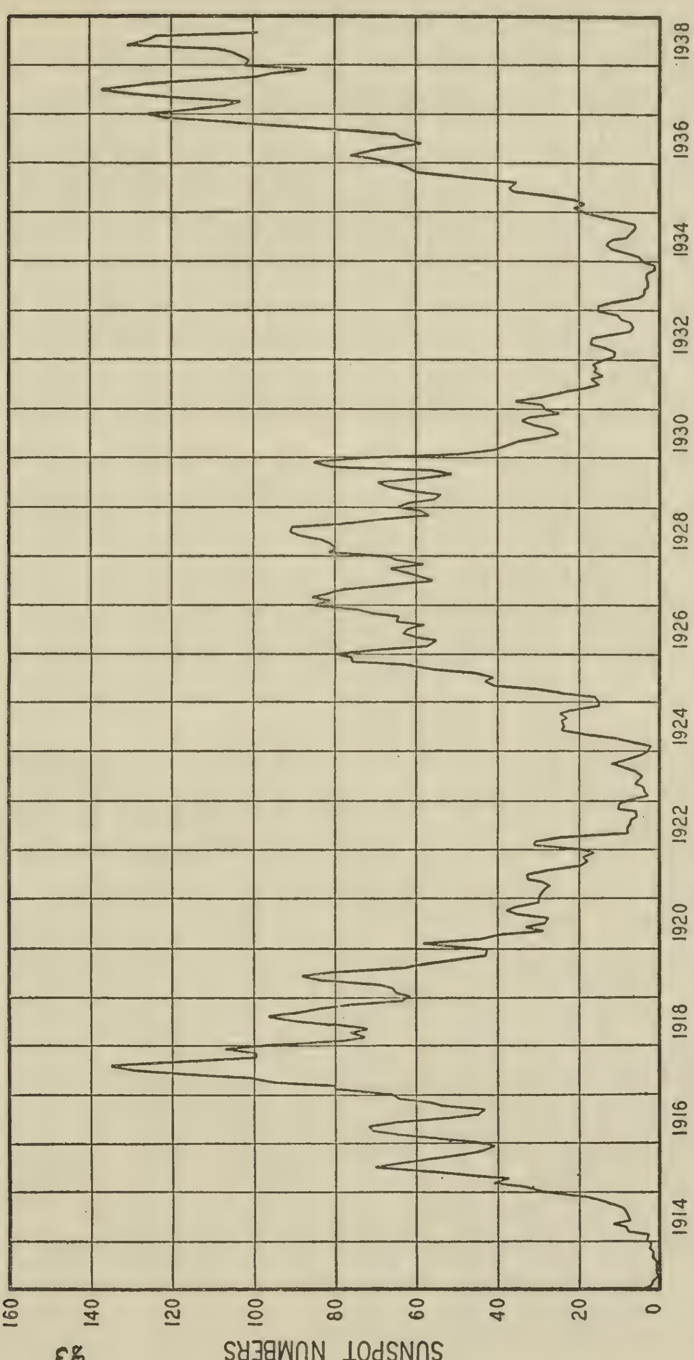


FIGURE 6.—Where we are in the present sunspot cycle. Three-month running means.

behavior of the sun. Of course the spots are fundamentally due to atmospheric disturbances in the surface layers of the sun. Whether the cause of these disturbances is to be found entirely within the sun itself, or whether there are extraneous causes for the phenomenal changes in solar behavior, we do not yet know. The periodic nature of the recurrences of sunspots has suggested to many that planets in some way are the disturbing bodies, but thus far predictions of sunspots based on planetary cycles have not met with much success.

Any complete theory of sunspots must obviously express not only why they arise at more or less irregular intervals of about 11 years, but also why the spots of a new series first appear at high solar latitudes. It must also account for the progression of the spots toward the solar equator as the cycle advances. Furthermore, since it is definitely known that the magnetic character of the spots changes from

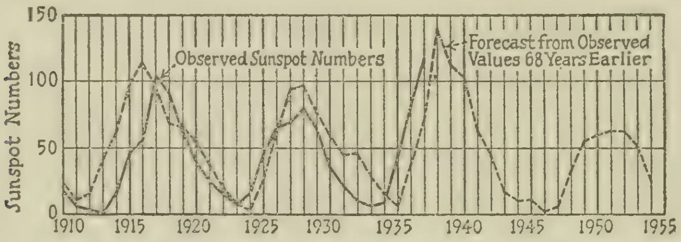


FIGURE 7.—Clayton's prediction of sunspot maxima based on 68-year period.

one cycle to the next, an explanation is needed for the change in polarity of sunspots in alternate cycles. Professor Bjerknes, a Norwegian meteorologist, has attacked the problem on theoretical grounds. He supposes that there is an atmospheric circulation taking place between the outer surface of the sun and the interior in such a way that in the outer layer of the solar activity, the gases are flowing from the poles to the equator. Near the equator he conjectures that they fall below the surface and then travel northward to high latitudes again. Gaining in temperature through their subsurface migration, these currents rise again to the surface around latitude 40°, proceed once more toward the equator, losing temperatures by radiation, until they fall again into the interior when the solar equator is reached. Accompanying such a circulation on a gigantic scale, the author of this theory postulates that secondary whirls will arise extending into tubular formation. Occasionally forced to the surface, the tube breaks into two segments, the ends of which appear as a pair of sunspots. A single spot would be the result of but one end of the tube appearing at the surface.

To account for the change in polarity in alternate cycles, he supposes that while one tubular formation is in progress, another vortex rotating in the opposite direction exists in the lower region and is carried for-

ward to break out at high latitudes, characteristic of the next cycle. He assumes it would take some 11 years for one family of tubular vortices to descend from the high latitudes to the equator while the second subsurface vortices with inverse polarity move northward for the start of the new cycle.

While Bjerknes thus accounts for many of the well-observed peculiarities of sunspots by this theory, he gives no satisfactory explanation of the origin of these circulating tubes of gas nor is any attempt made in his theory to account for the 11-year periodicity together with the slight variation in this 11-year interval.

The question of what causes sunspots and why they wax and wane in cycles is not yet answered. Most astrophysicists would dismiss any attempt at predicting the cycle on the grounds that the chief cause of sunspots lies within the sun itself and perhaps is inevitably irregular in its action.

Many investigators, on the other hand, have held to the idea that the tidal forces of the planets acting on the solar atmosphere may be the ultimate cause of the cyclical disturbance. Attempts to predict in advance sunspot maxima, however, on the basis of planetary periods has not met with much success. There is one element, perhaps, in any planetary theory of sunspots that so far as I am aware has not been previously considered, and that is the part played by the period of the sun's rotation itself.

On the basis of any equilibrium tidal theory, we should expect that the tide-producing force from any planet, no matter how feeble, should produce two tidal bulges directly opposite. A given region in the solar atmosphere, therefore, will be subject to two periods of tidal stress during each revolution of the surface with respect to a given planet. In the case of a slow-moving planet such as Jupiter, the interval between these tidal stresses would be about 12.5 days at the solar equator. If, now, there were a free period in the solar atmosphere very nearly equal to this forced period of 12.5 days, an oscillation might be set up which would ultimately reach a maximum and then subside again unless the two periods were exactly commensurate. The length of time between the times of maximum oscillation would therefore depend upon the ratio of the free period of the solar atmosphere to that of the rotation of the sun with respect to the planet in question.

It is conceivable that such an oscillation might reach a maximum in the case of Jupiter in an interval of possibly as long as 11 years. The fact that this interval might nearly equal the time of revolution of Jupiter about the sun—11.8 years—would be merely a matter of coincidence.

In the case of a more swiftly moving planet such as the Earth, Venus, or Mercury, the rotation with respect to these nearer planets

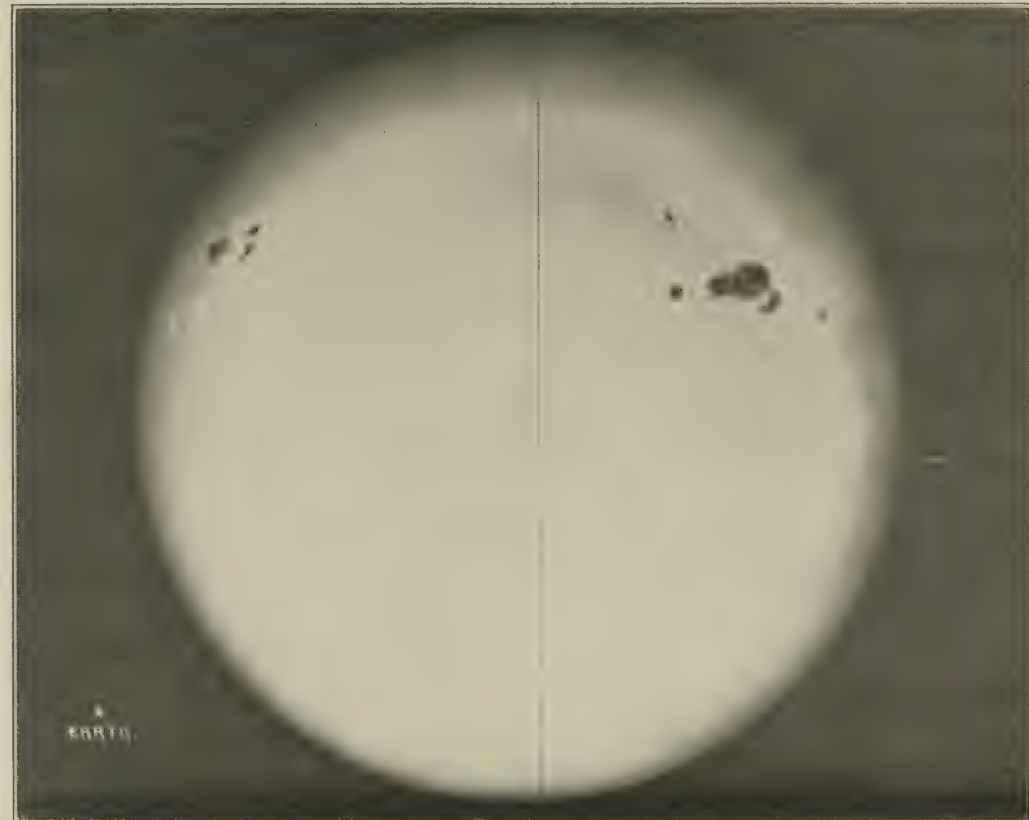
would consume a somewhat longer time and the interval between periods of maximum oscillation of the solar atmosphere resulting would be very different from what it is in the case of Jupiter. It must be borne in mind that from the point of view of the tidal effect on the sun, the tide-raising forces of Venus and Mercury and the Earth are not much inferior to that of the planet Jupiter. When we know more about the hydrodynamics of the solar atmosphere so that it will be possible with reasonable assumptions to calculate the anticipated periods of free oscillations, we might then have a quantitative method for testing the validity of such a hypothesis.

The theory lends itself to considerable elasticity since at higher solar latitudes where the tangential tidal force is greatest, the period of rotation of the sun is considerably longer than at the equator. One might expect on such a hypothesis that the observed sunspot period would be the resultant of several oscillatory waves set up by the several planets. The composite curve might, under selected conditions, have a mean period between maxima equal to the known sunspot period of 11.3 years, and in many instances there would be wide variations from the mean of this cycle.

This theory would be consistent with the fact that the spots originate in the region of the 40° latitude zone where the tangential component of the tidal forces tend to a maximum, and not inconsistent with their subsequent migration toward the solar equator. Until a mathematical treatment of free oscillations in the sun based upon more information than is available at present can substantiate such a hypothesis, we can but continue to speculate.

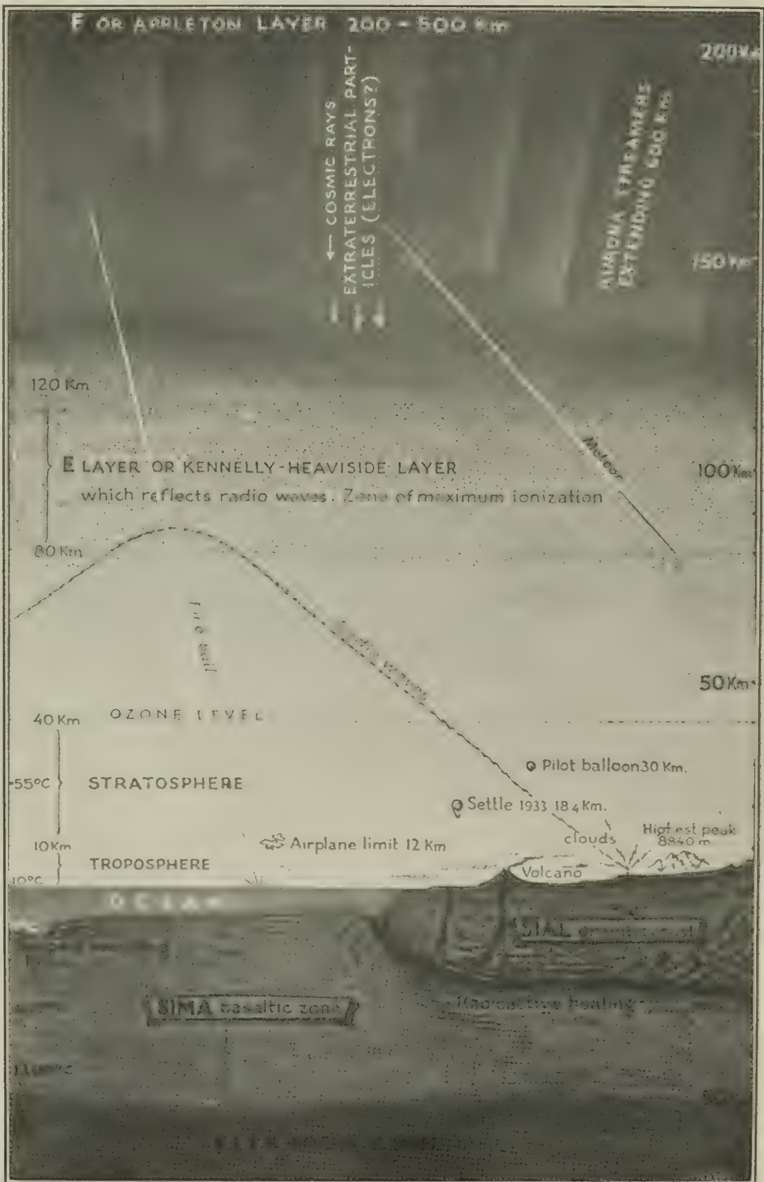
In the space of an hour we have seen a few of the important ways in which the sun and the atmosphere with a balanced nicety provide the essentials of life. We find that changes in the sun find quick response in this atmospheric envelope which surrounds us. Climate, weather, radio communication, and perchance terrestrial effects yet to be discovered may some day become predictable through cycles that follow law and order. Is it possible that astronomy, the oldest of the sciences, which first intrigued man's study of the sky in the hope of guiding human destiny, may once more be turned again to earth and, with the knowledge gained from suns and galaxies, lead mankind to a more intelligent adjustment of life to its cosmic environment for the betterment of all?

If such is but a dream, it is at least a dream well worth the quest. We may surmise that in our search the guiding star of human destiny will be the sun.

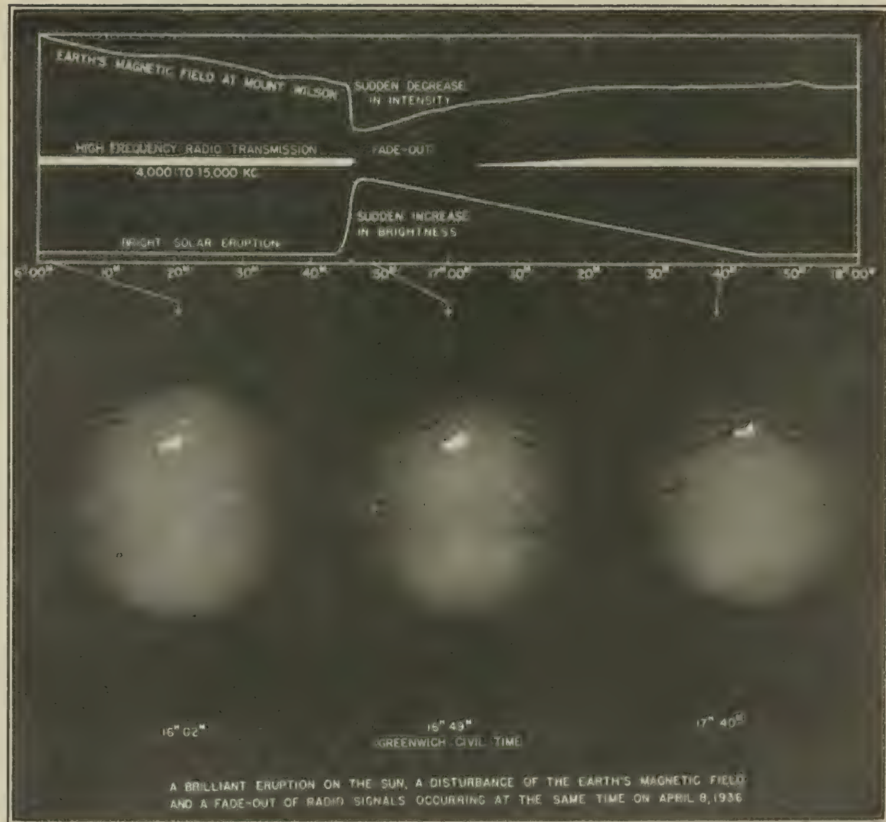


THE SUN, SHOWING LARGE SUNSPOT GROUPS OF JUNE 15, 1938, PRECEDING MAGNETIC STORMS AND BRILLIANT AURORAL DISPLAYS.

(Photographed with 40-foot solar telescope of Cook Observatory.)



CROSS SECTION OF EARTH'S CRUST AND ITS ATMOSPHERE.



RADIO FADE-OUTS AND MAGNETIC DISTURBANCES ACCOMPANY VIOLENT SOLAR OUTBURST.

(Courtesy of R. S. Richardson, Mount Wilson Observatory.)

COSMIC RADIATION [1]

By P. M. S. Blackett, M. A., F. R. S.
Professor of Physics, Birkbeck College, University of London

The study of cosmic radiation is rather a curious one. It is related ultimately both to astronomy, to geophysics, and to physics. The subject started about 1900 with the discovery by C. T. R. Wilson, and by Elster and Geitel, that the air in a closed vessel had a slight residual conductivity. The apparatus used for these early experiments consisted of an ionization chamber. A simple form of this apparatus consists in a metal box in which is suspended an insulated wire carrying a gold leaf; when charged electrically, the movement of this leaf records the electrical conductivity of the gas in the box. With such a simple apparatus as this it was found that there was a residual conductivity of the air, which could not be explained by the effects of the known radioactivity of the earth's crust, and which was probably due to the presence of some very penetrating radiation. In fact, C. T. R. Wilson himself, in 1901, speculated as to whether this residual ionization might not be due to some radiation coming from sources outside the atmosphere, either electromagnetic radiation, like X-rays, or corpuscular rays, like cathode rays, but of enormously greater penetrating power. Since that time at least 1,000 researches have been made on the subject of cosmic rays and a great many facts have been found out. We know now that this residual ionization is, in fact, due to atomic particles of enormous penetrating power coming into the earth's atmosphere from some sources outside the solar system, but exactly what these particles are, or where they come from, or how they were formed, or when, we still do not know.

In this first lecture I am going to describe mainly the researches on cosmic rays which have been made with the ionization chamber as the instrument for their detection. There are, in addition, two other instruments by which these rays are detected and measured, and these will form the subject of the two succeeding lectures.

Soon after the earliest experiments ionization chambers were taken to different places on the earth to find out whether this residual ionization varied from place to place. Then a great series of experiments began in which ionization chambers were taken up mountains, in balloons, lowered down to the depths of the sea and carried in aero-

[1] The first of three lectures delivered before the Royal Society of Arts. Reprinted by permission from the Journal of the Royal Society of Arts, vol. 85, No. 4421, August 13, 1937.

planes. The crucial experiments, which showed the cosmic nature of the rays, were those of Hess in 1911 and 1912, who took ionization chambers to a height of 5,000 m in balloons. Hess found that the ionization due to the rays was larger at a great height than at sea level. This showed conclusively that the rays causing the ionization must have come downward from the top of the atmosphere, and not upward

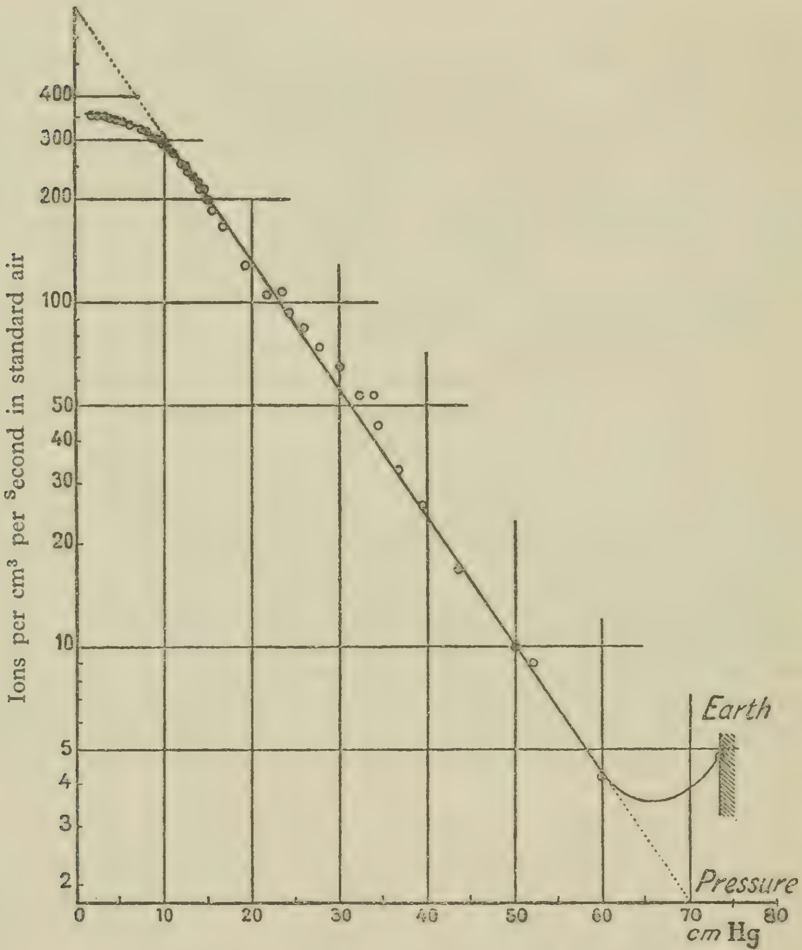


FIGURE 1.—Atmospheric pressure (Piccard, Kipfer & Cosyns).

from the earth; for if they had come upward from the earth, they would decrease in intensity by absorption as one went up. Hess also found that the rays were equally intense both during the day and at night, and also during an eclipse of the sun. This showed that the rays could not come from the sun, because if they had, their intensity would be much less at night, or during an eclipse. Thus it was these experiments which led to the rays acquiring the name of "cosmic."

Since that time a very great number of experiments have been made to find out how the cosmic radiation varies in intensity in the atmosphere. Perhaps the most beautiful of these, and the most successful, have been the balloon flights of Regener and lately those of Millikan, who send very light recording apparatus up to great heights by means of small hydrogen-filled rubber balloons. A small ionization chamber, which is made to record automatically the intensity of the rays on a photographic plate, together with the barometric height and the temperature, is made to weigh only a few pounds. This is enclosed in a light frame covered with cellophane, which acts like an ordinary greenhouse; the sun's rays coming in through the cellophane get degraded into heat and cannot get out again. In this way the apparatus is kept warm at about room temperature, even though the temperature outside the apparatus is $-50°$ centigrade. The rubber balloons which are used to take the apparatus up have to be examined very carefully for small pinholes, otherwise they are apt to burst prematurely, before the desired height is reached. Professor Regener sometimes has to stop up 100 or so tiny holes with rubber solution before using a balloon. With such an apparatus, heights of 30 km above the surface of the earth have been reached, where the pressure of the atmosphere is only about 1 percent of that at sea level. It is found that the intensity of cosmic radiation is about 200 times as great as on the ground, confirming, of course, the view of Hess that wherever it is the rays come from it is at least outside the earth's atmosphere. Figure 1 shows a typical curve of the variation of the ionization with the pressure of the atmosphere.

With similar, but much larger apparatus, the ionization due to cosmic radiation has been studied under water, down to great depths. Regener, again, has measured the ionization down to depths of 280 m below the surface of Lake Constance, and finds that their intensity is only about 1 percent of that at sea level. So from the bottom of Lake Constance to the top of the stratosphere the intensity of cosmic rays increases by a factor of over 10,000 to 1. The enormous penetration of the rays, a penetration quite unexpected in the region of atomic physics, leads naturally to the conclusion that the rays must be of immense energy. The most penetrating atomic rays previously known, the beta rays from radium, can only penetrate a few centimeters of water. Thus, the cosmic radiation is many hundred times more penetrating, and is, therefore, likely to be very much more energetic. In fact, it can be easily estimated that, to explain the very great penetrating power of some of the rays, it is necessary to assume energies up to 10^{11} electron volts.

The next great series of experiments consisted in the carrying of ionization chambers all over the world. Expeditions to the equator, to near the north magnetic pole, expeditions on mountains and in

ships, all these have been used to find out how the intensity of cosmic radiation varies with the latitude and longitude and the height of the place of observation. This aspect of the study of cosmic rays can be

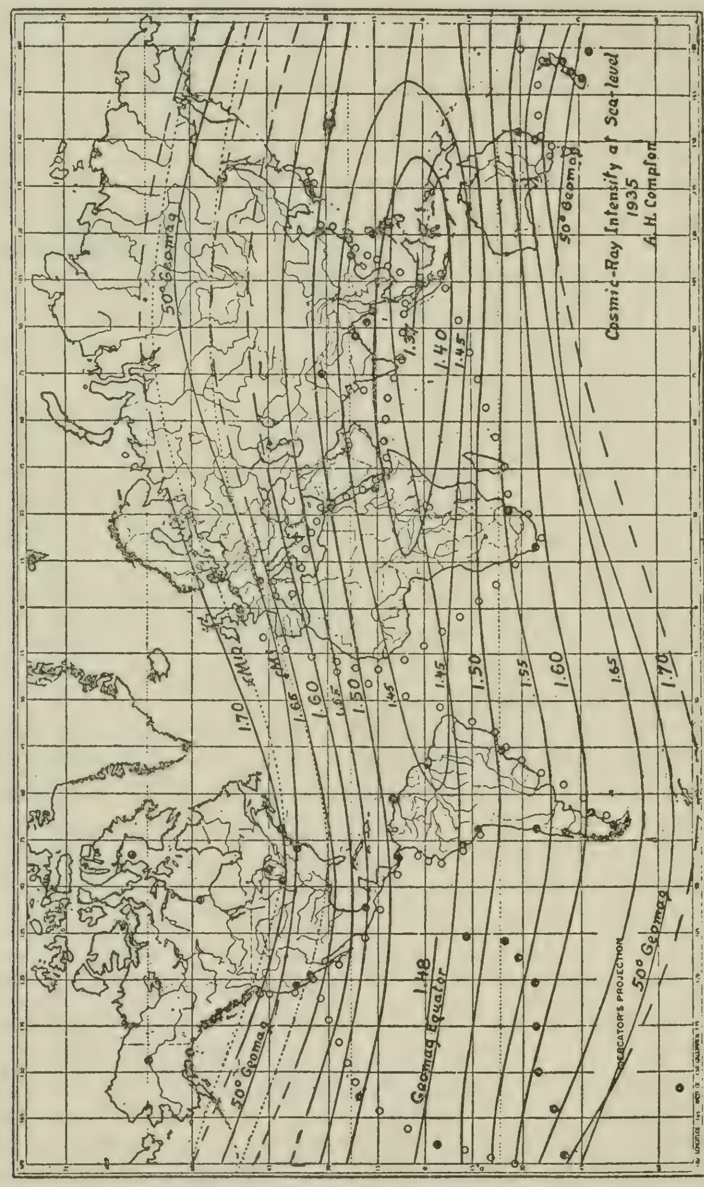


FIGURE 2.—Curves of equal cosmic-ray intensity (isocosms) showing approximate parallelism with parallels of geomagnetic latitude and with curves of equal auroral intensity.

called the geophysical aspect and is, in fact, closely related to the study of the variation of the earth's magnetic field over the surface of the earth. In figure 2 are shown the lines of equal cosmic ray intensity—or isocosmic lines, as they are called—and these lines run very

nearly parallel to the lines of equal geomagnetic latitude. They also run nearly parallel to the lines of equal auroral frequency. The explanation of this relation will be mainly left to the next lecture, but can be given shortly by saying that the cosmic rays as they reach the upper levels of the earth's atmosphere are mainly electrically charged particles of very great energy. These particles are deflected by the magnetic field of the earth so as to reach regions of higher latitude more easily than regions near the equator. This behavior is very similar to that of the charged electrical particles which are held to be the origin of the northern lights. In fact, the theory of the aurora polaris, proposed many years ago by Birkeland and Störmer,

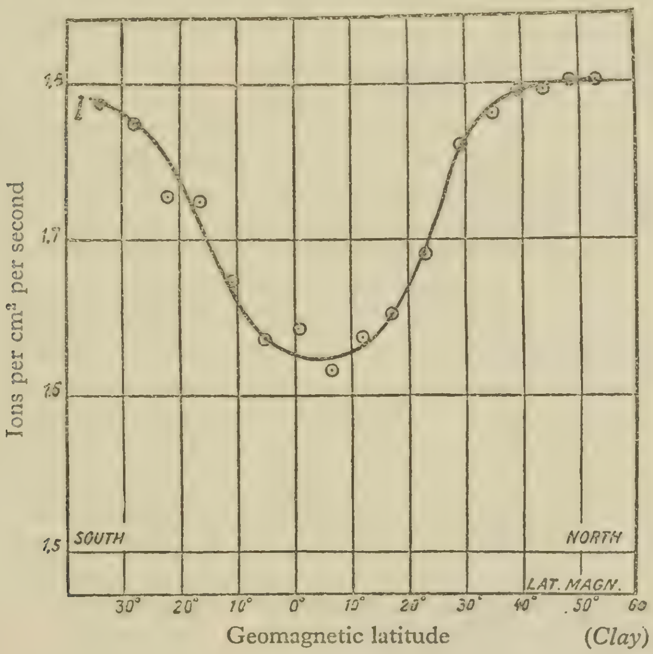


FIGURE 3.

applies almost unchanged to cosmic radiation. The intensity of cosmic radiation is found to be nearly constant from latitude 50° north up to the poles, but decreases toward the magnetic equator, the decrease amounting to about 15 percent. Figure 3 shows the results obtained during a voyage from Southampton to Cape Town. At greater heights, the increase from the equator to the poles is much greater.

This study of the intensity of cosmic radiation at great heights and in different latitudes is of the highest importance, but our knowledge is at present extremely fragmentary and quite inadequate for many purposes. In order to test theories as to the nature and behavior of

the rays, we really want to know the intensity of the cosmic radiation from sea level right to the top of the atmosphere at all latitudes, but so far it has not been possible to do many experiments of this type.

Apart from the free balloon ascents by the technique already described, valuable results have been obtained by the use of manned balloons. This technique was first developed by Professor Piccard. It is well known that it is not possible to live at a height above, say, 20,000 feet, without the use of oxygen—at least, if one cannot spend a long time acclimatizing oneself to the reduced pressure. One can go to a height of 40,000 feet or so if one breathes oxygen instead of air, but one cannot go very much higher, even breathing pure oxygen, unless one keeps up the pressure of the body artificially. There are two ways of doing this: one can place oneself, as did Professor Piccard, in a metal gondola, generally of spherical shape, which is sealed up and retains the pressure on the body above that of the air outside. The other method is to use a pressure suit, that is a suit rather like a diver's suit, but in which the pressure is kept above that of the atmosphere. This method was used in setting up the recent altitude record for aeroplanes. With the former method Piccard and his collaborators and also some other investigators in America have reached heights up to 18 km, carrying elaborate and heavy apparatus with them. In one such flight from Belgium, which ended up somewhere in Central Europe, Dr. Cosyns measured the variation of the intensity of cosmic rays as he floated across Europe at a height of some 12 km. He found, much to his surprise, that the cosmic radiation remained constant from about 51° north to about 49° north, and then dropped suddenly as he went farther away from the poles. This critical latitude of 49° north, above which the cosmic radiation remains constant, is of great importance in all cosmic ray theory. We have to try and explain exactly why the cosmic rays remain constant north of this latitude both at sea level and at great heights. At present there is no satisfactory explanation of these facts.

The next part of the study of cosmic radiation to be described is how the intensity varies with the time. Experiments have been made over periods of years to see if the cosmic radiation is quite constant or if, and how, it varies. Some results are shown in figure 4. The soft components of radiation, that is the part of the radiation which has not a very great penetrating power, does show an appreciable variation with the time of day. There is a slight maximum about midday of the order of a few percent of the whole intensity. But when the soft radiation is filtered out by means of thick lead screens, the remaining penetrating component is found to be almost constant. The figure shows that this penetrating component does not vary more than a fraction of 1 percent throughout the day; that is, when the results are averaged over a very large number of days. This again shows, as

did the early experiments of Hess, that the radiation cannot come from the sun—at least, if it travels in straight lines—for if it came from the sun it would be very much more intense by day than by night. One can, in fact, conclude from the constancy of the radiation with time that the rays, as they reach the earth, must be isotropic; that is, they must be coming from all directions equally; for if they were coming from any one direction predominantly, then since the earth is rotating, any part of the earth's surface would receive more radiation when it was facing the direction from which more rays were coming. Thus, the constancy in time of the rays implies their isotropy in space. Now this is one of the most difficult things to explain about the cosmic rays, for it is very difficult to find plausible sources for the rays which are uniformly distributed with regard to the earth. As has been mentioned already, the sun is obviously excluded as a possible origin, but so also are the stars of our galactic system, for these are far from being uniformly distributed around the earth. If one looks at the night sky one sees a great concentration of stars which we call the Milky Way. There are many times more stars in this direction than in a direction at right-angles, so if the rays came from the stars of the Milky Way there would be a greater intensity of the rays when the Milky Way is overhead. This means that the rays would show a variation with sidereal time, but careful

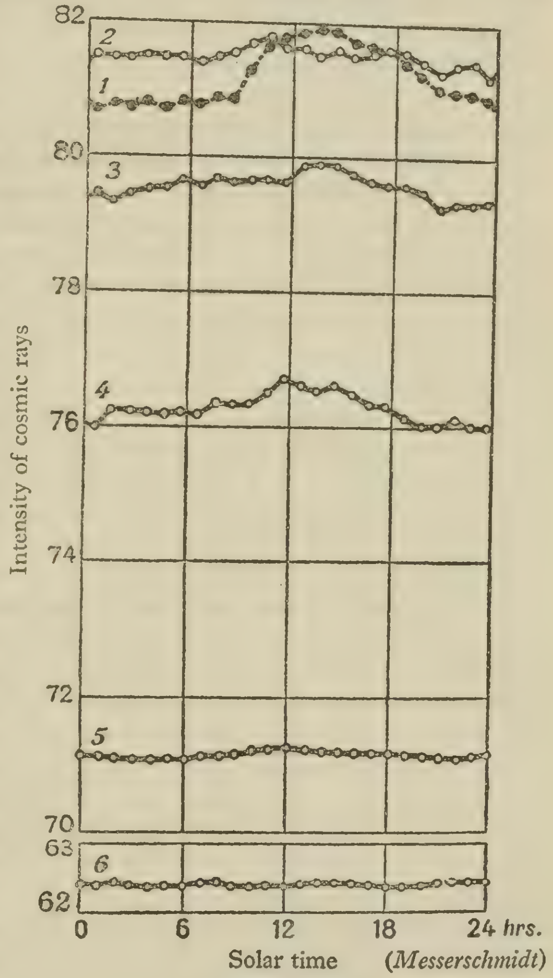


FIGURE 4.—Absorber.

1. None.
2. Absorber 0.5 cm Pb.
3. Absorber 1.5 cm Pb.
4. Absorber 3 cm Pb.
5. Absorber 10 cm Pb.
6. Absorber 20 cm Pb.

investigations have shown that there is very little variation indeed. There is a small effect, which will be discussed later, which is of great importance and which has only recently been detected, but the variation with sidereal time is very much less than would be expected if the stars of the Milky Way were the origin of the rays.[2]

Now all the stars that one sees with the naked eye, or can be seen even with a large telescope, are members of a huge group of stars called the galactic system. This system contains some 30,000 million stars. These stars form a kind of huge flattened disk, of which the size can be roughly estimated as being 60,000 light years in diameter and 5,000 light years thick. It may be noted that a light year, which is the unit of distance often used by astronomers, is the distance traveled by a ray of light in a year, and is about 10^{13} km. About 90 percent of the matter in the galactic system lies in this central flattened disk, about half consisting of stars and about half of diffuse matter and of gas. The earth is situated somewhere near the central plane of the disk, but about 20,000 light years from its center. This whole galactic system constitutes a huge nebula analogous to, but probably rather larger than, the great spiral nebula in Andromeda. There is a great central condensation of stars near its center which lies toward the constellation of Sagittarius, this constellation lying in about the thickest part of the Milky Way. In recent years it has been discovered that the whole galactic system is in rotation, making one complete revolution in about 250 million years. Since the earth lies so far from the center, it is traveling through space with a very large velocity, amounting approximately to about 300 km per second. It can be shown that the effect of this large velocity is to make the intensity of cosmic radiation slightly greater on the side of the earth which faces the direction of motion, as compared with the opposite side. Just in the same way as more raindrops are found on the windscreen of a moving car than on the back window, so the motion of the earth is revealed by the greater intensity of cosmic rays on one side. This fact was predicted by Compton, and has been recently found experimentally. The variation is quite small, being less than 1 percent in magnitude, but it seems fairly clear from the measurements of Hess and Steinmaurer Schonland and of Kohlhörster, that the predicted variation does really exist. This is a very important result, for it confirms the view, that I have mentioned above, that the cosmic radiation cannot have its origin in our own galaxy. Figure 5 shows the results of the variation with sidereal time which confirm Compton's predictions.[3]

---

[2] *Note in proof, February 1939.*—It is now thought that there may be a sufficiently large magnetic field throughout the galaxy to deflect the rays very considerably. If this is the case, the above argument is invalid, and so the galaxy still remains a possible place of origin of the rays.

[3] *Note in proof, February 1939.*—More recent measurements and calculations have thrown great doubt on the existence of a variation with siderial time of the magnitude demanded by Compton's theory.

It is of interest to note that if the earth had been completely covered with cloud so that no stars could ever have been seen, it would still have been possible to show that the earth was moving very rapidly toward a certain direction in the heavens, or, more accurately, moving relative to something, the only property of the something being the power of producing cosmic rays. We will take it, therefore, that it is experimentally demonstrated that the cosmic rays are of extragalactic origin.

We must, therefore, seek for some extragalactic origin for the rays which is uniformly distributed all round the earth. Now there are such bodies—in fact, the whole universe is filled with nebulae—and these nebulae are, in fact, nearly uniformly distributed around us.

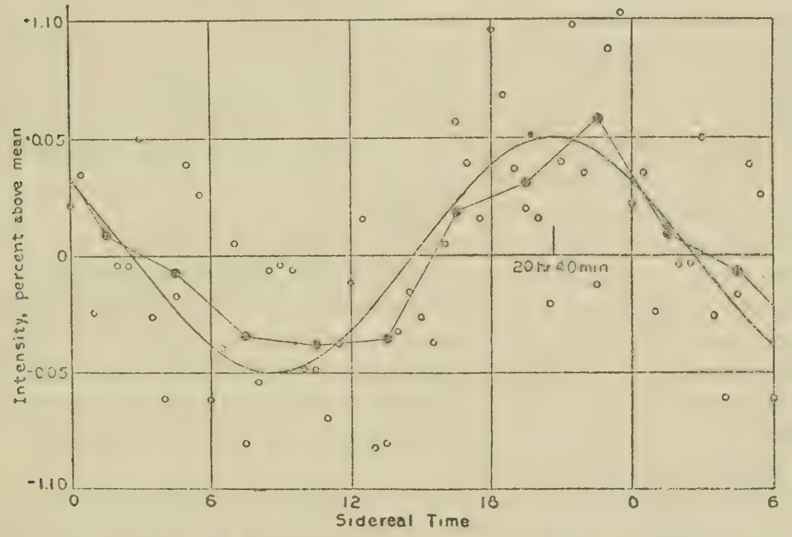


FIGURE 5.—Percentage variation in intensity of the cosmic rays with sidereal time. Curve, predicted effect due to galactic rotation. Data, Hess and Steinmaurer; open circles, half-hour means; solid circles, 3-hour means (Compton).

Each nebula may be considered to be another galaxy similar in principle to our own, but in general of rather smaller size. But if we imagine that these nebulae are the origin of the cosmic rays, we meet with a great difficulty, for it has been shown that the rays do not come from our own galaxy, so why should they come from any other galaxy? These nebulae are of widely different types, but it seems probable that these different forms represent mainly different stages in very similar life histories. The youngest nebulae seem to consist of a great mass of diffuse gas which gradually condenses into stars, and develops finally, in many cases, into a spiral form such as is shown by the great nebula of Andromeda. Our galaxy is probably a nebula of this last type. Thus, it is, of course, possible that the

cosmic rays are produced by nebulae in the early stages of their existence, but not in the later stages such as our galaxy is in now.

There is another reason why the cosmic rays are unlikely to be produced by the stars in ordinary nebulae. This is the fact that the outside layers of nearly all stars are rather similar. These outside layers consist of a gaseous envelope at a temperature of, say, between 5,000 and 20,000 degrees centigrade. Now since we know that the sun does not produce cosmic rays, it is difficult to see why other stars, which have rather similar surface conditions, should do so. There are exceptions to this general similarity of the outside of the stars. The White Dwarfs are very small but very dense stars, and have surface conditions which are very different from that of our sun, and so might conceivably be considered possible origins for the rays. It must be remembered that cosmic rays, although very penetrating from our terrestrial standpoint in that they can penetrate some thousand meters of water, cannot be considered penetrating from the point of view of a stellar atmosphere. Any cosmic ray which was produced inside a star would never get out. It is thus clear that it is only from the outer layers of a star that the rays could come, and these outer layers are nearly all alike.

Many other possible explanations of the origin of the rays have been given, but none put forward hitherto seem very plausible. It is possible, of course, that the rays have their origin in electric fields in extragalactic space, but there is no real reason to believe that such fields exist, and it is difficult, perhaps, to explain on this basis the isotropy of the rays. Then, Swann has suggested that they have their origin in sunspots—not sunspots in the sun, of course, but postulated spots in giant stars.

Milne has predicted the existence of rays of very great energy from his cosmological theory. This theory requires also the existence of uncharged particles as well as electrically charged particles.

Zwicky and Baade have sought the origin of the rays in the supernovae, that once every few hundred years appear in every nebula and grow to huge intensity for a period of a few weeks. Another class of suggested origins are the archeological hypotheses. The arguments in favor of these views are roughly as follows. It is very hard to find an origin here and now in the universe for the cosmic rays, so perhaps they were formed at the very beginning of time when the world was quite young and, supposedly, very different. It is, of course, obvious that if they have come from a very great distance they must have their origin in the distant past. Lemaitre is an exponent of one of these theories. He supposes that the rays have their origin in some kind of superradioactive process from a single primeval nucleus, from which has developed the universe as we know it now; but, as there does not seem to be any possibility as yet of

testing or distinguishing between these numerous rival hypotheses, it is probably not worth while spending very much time on such speculation. One more ingenious origin may, however, be mentioned. It has been suggested by Alfvén that the rays arise from a kind of stellar cyclotron formed by the rotation of a double star. It is supposed that the combination of an electric field of one component of the double star, together with its magnetic field, may lead to the possibility of stable orbits for high-speed electrons very similar in principle to the orbits in the cyclotron of Lawrence; but here again no definite test of this hypothesis is possible.

A WORLD OF CHANGE[1]

By Edward R. Weidlein
Mellon Institute of Industrial Research, Pittsburgh, Pa.

The most interesting address that I could deliver to our radio audience would be to pick out at random from this distinguished group of chemists individual persons and describe their work to illustrate the application of science which has transformed the world. Here are gathered scientists from all parts of the United States, as well as representatives from foreign countries, to exchange ideas, and in their presence it would not take one long to realize that something startlingly new and extremely important is happening in the world.

Their gathering is important, and every university, research organization, and industry should be represented. Every chemist realizes that scientists stand upon the shoulders of their predecessors. It is for this reason that their gain is exceptionally rapid. A scientific principle once established becomes the property of all science; a piece of apparatus once constructed becomes a pattern for later apparatus of the same kind.

These leaders in the fields of science are the real authors of history. Their work is having more fundamental effects than all the laws that have been enacted or all the armies that have ever marched in triumph. The benefits that flow from their achievements are not limited by race or creed or political boundaries or even by time. They provide physical comforts for all men and gradually free their bodies from disease and their minds from the terrors of superstitions. They give their fellow scientists enchanting new views into the regions they explore.

That this influence does not die with the individual is clearly illustrated by the life of Charles Frederick Chandler, whose one hundredth birthday will be celebrated at Columbia University in October. Dr. Chandler was one of the founders of the American Chemical Society on April 6, 1876, and served as its president in 1881. He knew how, as few others who have lived, to open the portals of chemistry to a pleasing and attractive vista. He aroused curiosity and ardor. He

[1] Address of the president of the American Chemical Society, Rochester meeting, September 9, 1937. Reprinted by permission from Science, vol. 86, No. 2229, September 17, 1937.

was a mighty force in the introduction of chemistry into medicine. Wherever we go we find traces of this remarkable man—in industry, in sanitation, in the household and in the improvement, comfort, and safety of living. He was a great teacher, and his boys were his constant delight and ever-present care.

If one were to probe the methods of an intent, aproned man busy with the test-tubes, Bunsen burners, flasks, and reagents in a chemical laboratory, he would hear a story fashioned of numbers. Strange that the infinite variety of the universe can be resolved into a series of numbers! But to the chemist there is little that is strange about it. Nature has demonstrated that the seemingly endless variety of cosmic phenomena, ranging from microscopic dust particles to gigantic stellar systems, is, after all, superficial. For chemistry has reduced the universe to 92 chemical elements or kinds of atoms, starting with simple hydrogen and going up the atomic scale to uranium, the most complex element known. All that we see about us can be resolved into these elements. The fascinating realm of nature, from the log that blazes in one's fireplace to the snowcapped mountain chain that lures in summer, is built up from these elements and their various combinations—evidence of the infinite variety of ways in which atoms and molecules can be joined together. Joined in one way, they make a useful textile; in another, a nourishing food.

Not satisfied with the world as they see it, scientists have set their hands and minds to the task of changing the creations of nature or making new products which nature neglected to make. Nature makes her compounds for general purposes, and is not aware of industrial, scientific, nor medical needs. Hence nature is not perfect because not omniprovident, and the chemist often finds it necessary to improve on nature. Already he has prepared artificially a vast number of substances that nature never dreamed of making, including dyes unmatched by any flower, alloys that were not created when the earth was a cooling fiery ball, artificial silk and woolen fibers, stronger drugs and sweeter perfumes wrung from such a surprising source as coal-tar. Many products of life processes and a much larger number of new compounds related to them have been made by the chemist. He is changing life more rapidly and inexorably than ever before, and all about us are heard glowing words about "the new synthetic age."

Our future, to a large extent, is in these innocent-looking but all-powerful test-tubes that you will see neatly arranged, row upon row, in any laboratory.

If Aristotle were living today amid our chemical successes, his childhood belief in fairy stories probably would be reborn. The Greek philosopher interpreted the universe in only four elemental forms of matter—earth, air, water, and fire. These elements represented the four properties of dryness, cold, wetness, and warmth. Thus Aristotle

taught that all substances were composed of some sort of primordial stuff in combination with various amounts of the four elementary properties.

Out of Aristotle's doctrine of the elements grew the fascinating but futile work of the alchemists, who dreamed vainly of converting base metals into valuable gold. But, though futile, the efforts of the alchemists were not altogether fruitless. Modern chemistry had its beginnings in the mystical vaporings that characterized their gloomy, dimly lighted workshops, full of strange vessels, spheres, portions of skeletons hanging from the ceiling and massive parchment books covered with hieroglyphics. Alchemy may be compared to the man who told his sons that he had left them gold buried somewhere in his vineyard. The sons dug deeply and earnestly, but found no gold. Their cultivation of the soil, however, produced a plentiful vintage. Similarly, the earnest but unsuccessful search for the transmutation of base metals into gold brought to light many useful discoveries and instructive experiments.

These by-products of alchemy—chance discoveries of chemical elements, compounds and principles—were more important than the search for artificial gold.

The first investigator to grasp the significance of the value of chemistry as a separate science was Robert Boyle, whose publication of The Skyptical Chymist in 1661 is often regarded as marking the beginning of modern chemistry. Paracelsus, celebrated by Robert Browning, broke with the monks and alchemists, assailed the physicians who treated chickenpox with the aid of a soup made of the hearts and livers of vipers, and laid crudely the foundation of modern medical chemistry. Becher conceived of phlogiston as the active principle of fire. The downfall of the phlogiston theory began with the work of Joseph Priestley, preacher and scientist, who succeeded in isolating and identifying oxygen.

Before even Priestley, however, was Cavendish, shy, eccentric misanthrope, who played with chemical apparatus and weighed the earth, in preference to spending his wealth, and who won immortality as the first experimenter to reduce water to hydrogen and oxygen. But it was Lavoisier, later snatched from his laboratory by the French police to die under the guillotine, who molded chemistry into a science. The brilliant Frenchman, science's greatest loss to the Reign of Terror, formulated what is now known as the "law of the conservation of matter." This fundamental law states that in every chemical reaction the weight of the products is exactly equal to the weight of the substances which entered the reaction. Lavoisier also made a list of 33 chemical elements, explained the chemistry of fire and infused into the body of science a new spirit for accurate and patient measurement.

To ponder on the future life of man and on the ability of science to mold and reform the future is to lift oneself to a plane of high buoyance. In the words of the Earl of Balfour, in an address he made as president of the British Association, "The satisfaction it gives is almost esthetic in its intensity and quality. We feel the same sort of pleasurable shock as when, from the crest of some melancholy pass, we first see far below us the sudden glory of plain, river and mountain."

What woman or man but is interested in tomorrow? Judged by the scientific marvels of the present day, what an age it will be!

Photographs by radio; machines that seem to think; lights that pierce fog; gas made from water; cameras recording lightning bolts and taking pictures in the dark; 5-million-volt guns smashing atoms to wrest new secrets from nature.

News put into type by direct wire; machines to administer anesthetics, record telephone calls, and measure the billionth of an inch; other machines to measure the smoothness of roads and record the nature of accidents; ways to "hear" light and "see" sound.

Fantastic? Yes, but they're here.

These, and more, we have—although our elders would have scoffed if they had been told that these things would come. But a plane roaring from ocean to ocean between sunrise and sunset is nothing new. People talk across the ocean every day by telephone. The time may come when women will match fabrics by television, when their kitchens will make present-day luxury seem like the drudgery our grandmothers endured.

It is impossible, however, to fathom truly what tomorrow may be like. Only the rare human mind can free itself from the fetters of today's accepted forms and think in new terms of a different age. The first automobiles were cranked by hand. They broke many an arm, but people accepted the fact because no mechanical way of starting a car could ever work. Yet research, using a sleeve with threads like a screw, found a way to crank the motor; it had never dawned on science that it couldn't be done!

The pace of the advance has quickened. The resources of science, more closely knit, have speeded progress amazingly in the past 25 years. That pace will not slacken so long as human needs must be met. If what has happened already seems incredible, what are we likely to see in the not-distant future?

For we know full well that tomorrow probably won't resemble this age in the least. Too many "impossibilities" have come true in our own life-span. We have not yet forgotten that "man will never fly"; that conversing without wires was labeled an absurdity; that "nothing can ever be done" about typhoid, tuberculosis, or malaria.

Yet men have flown around the world, talked by wireless across the seas, stamped out plagues. The oxcart has made way for the

soaring plane; the laboring locomotive for its silent, streamlined cousin; the mechanical music box for the miracle of radio.

A finger moves a dial and invokes the human voice. But the telephone is an old story. Manufactured ice and mechanical refrigeration come instantly to the rescue in hot midsummer days. But we already forget the waste and illness of the era before man-made refrigeration. The photograph of a distinguished visitor spans the continent in a few seconds. Telephoto, too, however, becomes prosaic. A modern dryad wears a gown that last year was part of a tree. Yes, but we grow to expect beautiful new fabrics from the commonest substances, even glass.

If yesterday's miracles are today's commonplaces, what an age tomorrow may be, with science as its constant guide, insistent on solving human needs, making the improbable come true.

What kind of homes, for instance, shall we be living in by 2000 A. D.? What kind of furnishings shall we have? How shall we heat our homes? Shall we all be living in the country or in some new kind of city? What kinds of recreation shall we have? What kinds of planes, automobiles, trains? What kinds of bridges, tunnels, viaducts, ramps? What materials and substances shall we wear and eat? How much leisure shall we have for the art of living? We dare not more than guess.

For most prophecy is untrustworthy. We all are too likely to project the present into the future, forgetting that the future may go clear around us, or scrap much that we accept. Scientists speak casually of harnessing the winds for power, of drawing upon the heat of the sun, of using even the surge of the tides for power to replace fuel that by then may be gone. Laws will not prevent men from thinking. And so long as they think, so long as they refuse to accept the present age as perfect, advances will be made.

Back of all change is the wholesome spirit of discontent. There must be a way to make a better stocking, to create a more durable fabric, to make a better dust pan than those now sold. Dissatisfaction with something less than perfection, desires for something better, refusal to accept things as they are—these are the urges that lead to improvement. These, and a special quality of open-mindedness that keeps the present from closing the door to the future.

Chemistry is constantly seeking through research natural facts on which to base new truths, which bring about these changes. But she cannot invoke them alone, without the aid of her sister sciences, any one of which may at any moment find a new bit of knowledge which will lead the others along new trails. This world-wide collaboration is really the hope of scientific progress today.

Modern research is characterized by its complexity and the variety of phases which it presents. In the latter half of the past century and

the beginning of the present, it was still possible for an individual, working alone, with comparatively limited facilities, to achieve epoch-making results in the borderline fields of research. The surface has now been well explored and it is consequently necessary to probe deeper and to enlist the cooperation of trained specialists in such widely diversified fields as chemistry, physics, biology, and engineering. Elaborate equipment and apparatus are now required for the conduct of researches, for they must be performed on a mathematically correct basis with constant control of all variables.

There were ages when science moved haltingly or drooped in discouragement beneath the indifference of hostile rulers and superstitious peoples.

Today the speed of communications alone has woven the world of science more tightly, so that each bit of fresh knowledge is known everywhere as soon as it is proved. It no longer takes months for a new fact or method to filter from nation to nation, or years for it to be practically applied.

Considering the accelerated pace of recent years and the rate at which science has revolutionized our daily lives, it would be easy to sit back complacently and call this an age of scientific miracles, to remark that we had reached the ultimate in development, that there could be no more worlds to conquer.

It would be easy to say it, but your chemist, above all men, could tell you it is not true. He knows that chemistry, though brilliant its gains, has only scratched the surface—knows how pitifully meager is the hoard of knowledge so far acquired. In physics, in chemistry, in engineering, in medicine—the dearth of knowledge is the same. The swift progress that has been made must not make us overconfident and lose us that humility which we must retain if we are to be dispassionate searchers after truth.

If we take the time to glance back through the pages of history, we can see how easily each age has fallen into the error of believing that it represented the ultimate in civilization. There was a time when Europe, steeped in its troubles, guessed of no new land or opportunity like America. The Middle Ages seemed highly developed to its own peoples, but most of the great inventions and discoveries of science have come long since then. Even as late as 1900, millions felt that we had gained as much from science as we were likely to win. Yet in the short span of 35 years we have seen the first "red-devil" automobile become a necessity for the masses, turn transportation ideas upside down, revolutionize our industrial structure. We have seen radio burst upon the world and link distant lands by new seven-league boots. We have seen early ventures in flight give another dimension to transport. Television next, and meanwhile scores of new products, new foods, new industries of which, a generation ago, no one guessed.

Wonders indeed! Yet science realizes how truly little headway has been made, how much more remains to be done.

Scientific research is still young, even in the life of the universities, which are primarily responsible for its existence. Having gained the spirit of research from the universities, the industries have applied its methods to their own affairs with really amazing results. During the last 25 years the number of industrial research laboratories in the United States has grown from a very few to more than 2,000, which accounts for the great change that has taken place in our standard of living. It was chemistry, perhaps more than any other science, that taught business men the true significance of pure and applied research.

Without the evolution of scientific investigations in the universities, industrial laboratories might never have come into existence. Besides the very idea of research, the universities have furnished the industries with men possessing knowledge not only of the underlying scientific facts and theories but of the methods and techniques of investigational work. The man with a true scientific mind is always open to change. From the universities also proceeds much of the basic knowledge of science on which the industries of today have been built and which will be the foundation for the industries of the future. Accordingly, this essential contributory part of our universities should be recognized and nurtured by the industries. Colleges and schools have invested some $300,000,000 in chemical buildings and equipment. Real progress is made through the cooperation of pure science, industrial research, and the industrialists.

The expenditures for industrial research in this country have increased steadily. The chemical industry, the largest cultivator and supporter of research, has enlarged its expenditures on laboratory investigations; the food industry has likewise increased its appropriations for research. The metal-working field, which during the depression stopped much of its research, is now resuming laboratory investigations on a large scale. Researches have lately been accelerated in the fields of building materials, air conditioning, synthetic fibers, organic chemicals, plastics, "tray" agriculture, and new sources of motor fuel.

It may, moreover, be observed that the industries which engaged to the largest extent in scientific research emerged from the depression first and did the most to aid national recovery.

It must be remembered that it is only through applied knowledge that the people have gained the material blessings of our civilization. Every useful agent in our civilization is the product of our industry, and it is only through the industries that these new products of civilization can go to the people. New mechanisms, such as the telegraph, the telephone, the electric light, the X-ray, new medicines, dyes, and new alloys come to us only through the industries. We often hear it

said that some man eminent in science has "given" his results to the people. That is, in nearly every instance, nonsense. Röntgen's discovery of X-rays, upon which he took out no patents, could go to the people only by the use of X-ray bulbs, and these X-ray bulbs were manufactured and improved by various corporations, through whose factories they went to the people.

The classical example is, of course, the work of Faraday, on electromagnetic induction, on which is based ultimately the whole immense development of the electrical industry; a development not achieved, of course, without an enormous amount of capital and directed industrial research.

We are thinking, too, of industry not only depending upon many sciences but being in a real sense science itself. Science pursued in this broad manner will enrich itself and the world. The true manufacturing function consists in making the best thing possible in the most economical way. It does not mean practicing the art through the best tradition, but means pursuing the art with the aid of modern scientific knowledge. A good illustration is in the field of synthetic organic chemistry. The development of organic materials of predetermined characteristics to fill definite needs in industry has been employed on a wide scale only in recent years. The more common uses, such as the acetylene flame for cutting or joining metal shapes in the steel industry or the use of glycerol trinitrate or trinitro toluol as detonation agents in mining operations, are generally known. However, a wholly new degree of change is being brought about by interweaving of synthetic organic chemicals with other products. National defense against human aggressors as well as sanitary defense against microorganisms in their modern forms depend largely on synthetic organic chemicals as key products. The modern automobile and airplane, the outstanding accomplishments of the twentieth century to date, would be far from their present standard of excellence without the regulating effect of the synthetic products used in their construction and operation. Antiknock fuels, special lubricants, durable tires and other rubber goods, antifreeze materials, lacquer coatings, safety glass, brake fluids, plastic products, among other features, have permitted the remarkable degree of perfection and low cost which these unique products of our generation have attained. A new aliphatic organic chemical industry was created just prior to the depression and has had a rapid and continuous growth since 1929.

Research in the metallurgical industry has resulted in metals without which the production of these new aliphatic organic chemicals, and other processes, needing to be worked at high pressures and high temperatures, would have been impossible.

Chemistry has likewise played a major role in the production of better and cheaper motor fuel. Cracking, hydrogenation, polymeriza-

tion became common terms in the industry. The increasing demand for power plants has resulted in more severe conditions for the lubricants used. Automobile and airplane engine oils are exposed to high temperatures and greater loads each time there is an increase in the horsepower yield per cubic inch of cylinder capacity. Under these severe conditions oils are more likely to deteriorate and fail in service. Some progress is being made in the development of addition agents to oils for increasing the oiliness and film strength under severe conditions. By analogy with the well-established practice of adding antioxidants to gasoline to prevent gum formation, there is a development under way for adding antioxidants and similar inhibitors to lubricating oils. These may serve to prevent the formation of sludge by oxidation or to prevent corrosion of bearing surfaces, this by some mechanism not yet understood. It is possible that some of these difficulties may be eliminated by change of the engine design so that the lubricants will not be punished so severely. However this may develop, it is interesting to note that chemical research is suggesting a remedy for the engineering difficulty—difficulties caused by over-rapid engineering advances.

Our home-construction industry has received much criticism during recent years, and, as the basis of value received for cost and effort, it must be conceded that this criticism is largely deserved. Here is a field that has possibilities of a "world of change." That such a subject has reached the stage of public discussion, however, indicates that improvement has already begun. Our homes may not seem to us to be a chemical project but, in countless applications of plastic materials, quick-drying lacquers, and synthetic fibers, we may confidently expect new types of assembly to emerge with greatly reduced costs while giving sanitary, noiseless, fireproof, moisture-proof, and vermin-proof construction, in keeping with known possibilities. Let us take a simple example such as a cookstove. Practically every housewife complains of cooking over a hot stove in the summertime, and conditions are almost as difficult any time during the year. This inconvenience is caused by waste heat, which, if scientifically controlled, would eliminate the discomfort, economize on the fuel bill, and also save time. There has recently been constructed a stove along these scientific lines, using both new and old materials, which will give a heat efficiency of 80 percent instead of the average yield of 20 percent. In other words, 8 pounds of coal will cook sufficient food for a family of 12 per day. You are quite likely to see on the market in the future a combination coal cookstove and refrigerator in which the waste heat from the cook stove will operate the refrigeration unit. Glassware for cooking purposes has become a common article of commerce, but there was a time when glass was used only for windows and for ornamental purposes. The new tunnel under the Hudson River is to be

114728—39——14

lined with glass. The first all-glass building was recently constructed in North Carolina, and others are under construction. Glass in fibrous form will find its most widespread application as an insulating material for use in construction. Textiles made from glass, because of their resistance to acids, heat, and moisture, should find a variety of applications in both homes and industry. It is interesting to observe, however, that some of these new products are the ripening fruit of seeds planted many years ago. New mechanical devices and new application of basic scientific principles have made practicable the evolution of these new products. A good illustration is tempered glass, which was experimented with as early as 1875, and has only recently become a commercial product. The mechanical ice box did not come into its own until chemistry supplied the proper refrigerants. The home-construction industry can hardly yet be said to have started its real race.

It is believed that through orderly and persistent research industry will also be able to absorb much of the surplus crops of American farms. Cellulose is "stored sunshine." The alchemists talked of storing sunshine, the English speculators of the time of John Law floated companies for the purpose, the chemical industry of the future will harness sunshine in the form of agricultural byproducts and convert them into useful materials.

A striking aspect of the march of organized research is the emphasis in recent years on staple commodities, particularly those of agricultural origin, as industrial raw materials. New products have naturally been forced to pave their way to public acceptance by technical information obtained in the laboratory. The volumes involved in each case were, of course, at first small, in fact so insignificant that they were disregarded by the industries they were affecting. Change is too often considered as a sudden movement, which is misleading, as it is more often a gradual evolution.

To state the situation another way, new products were continually coming into prominence through the pressure of research, while the materials they were in part displacing lacked the informative background necessary to meet this aggressive competition.

As a tangible example, the case of cotton may be mentioned. All the world is familiar with the giant strides of rayon, its "college-trained" rival. On top of such competition comes the falling off of export volume, as a result of increasing quantities of cotton grown abroad.

Forward-looking men with constructive ideas on means of improving the economic condition of the South see here a great need for a vigorous research program of the cotton industry. Many of our Southern States are dependent on this one crop, and their people are trained, their industries are geared to a one-crop economy.

It is significant that developments in increasing the utilization of cotton have in the past been made almost altogether without any concerted action or conscious direction on the part of the cotton industry. This situation encourages one to believe that systematic, cooperative effort on the part of growers, manufacturers, and various research organizations, in developing new uses for cotton and in expanding present uses, should be much more effective in stimulating increased demand than haphazard, individual effort.

Sugar is another product that is vital in our national economic and social system. Sugar occupies an important place in the normal diet of all the people. It likewise is one of the cheapest, purest raw materials available upon which to base a new chemical industry. This new industry is now in the process of evolution, and today chemicals made from sugar are entering into our industrial processes to produce new and better products.

The scientists are doing the fundamental work. Industry is pioneering the commercialization of these new products, and eventually the agriculturist will have to supply the raw material because of the new demand created. So one often may know where a research begins, but rarely where it will end.

All this requires knowledge, will, and action. The knowledge which will find these new uses is a product of research. It will come out of the laboratory where the chemist is breaking down the raw materials we call cotton, sweetpotatoes, and corn into cellulose and starch and these again into the tiny atoms of which they are constituted. It is these atoms that are the chemist's raw materials. He may buy them in the form of cotton or soybeans or milk, but he sells them in the form of rayon, automobile parts, organic acids, new glues and gums and dextrins, new building materials for our homes, new paints and varnishes. These new uses require as raw materials the molecular aggregates which we take off the land in annual crops. It is true that the chemist can synthesize them in his laboratory, and some of them he will undoubtedly produce there, but this year and for many years to come the sunshine and the rain, the fertility of our soils, and the patient labor of our farmers will grow the crops industry needs more cheaply than the chemist can make them.

The better living conditions secured through the increased wealth provided by science, together with the application of science to hygiene and medicine, have considerably increased the average expectancy of life. This great achievement in public health is sufficient to justify the belief that those who call our industrial civilization mean in quality have narrow views and scant idealism.

Chemistry and medicine are establishing a more cooperative program of research, and a good example is some work that has been under way since 1926 on the treatment of pneumonia.

The results of this teamwork between chemists and medical scientists have been of outstanding importance. Woven throughout the whole progress of the investigation is ample human drama cloaked from the layman by such chemical names as hydroxyethylhydrocupreine, apocupreine, ethylapocupreine, hydroxyethylapocupreine, and other necessarily abstruse terms. Briefly, the problem was less to find a compound effective with pneumonia and allied diseases than to find one that would not harm the eyes. Certain of the cinchona alkaloids were known to be effective in treating pneumonia, but they were not to be used without great probability of eye damage. Such a dilemma is, of course, a challenge to the chemist and to the physician. The results so far indicate the discovery of cinchona alkaloid derivatives, as new compounds, which give the profession of medicine what it has long sought—a safe treatment of all types of pneumonia which will not harm the human eye and therefore can be both effective and safe.

To date, close to 80 preparations have been tested biologically by the medical collaborators. Some were found to cause no eye disturbance, but to have little activity with pneumonia. The most promising drug found, showing greater activity against the disease, lower toxicity than any of the others, has also been tested in scores of clinical cases, which have demonstrated a very high tolerance in the human being to the drug, absence of any untoward visual results and a high proportion of recoveries from severe pneumococcic infections of all types.

The investigations must go on, the clinical trials must be conducted on a wider base, production of the compound on a large scale must be undertaken. All these projects are now under way, and the chances of ultimate success are very promising.

When trained minds and proper facilities are applied to specific problems, practical solutions are expected. If they were not forthcoming—that would be news.

Fifty years ago, Europe led the world, chemically speaking. Farseeing men predicted even then that in another half-turn of the century the chemical leadership of the world would pass to America. This change has come about, and the American Chemical Society as an organization deserves a large share of the credit. The scientists of each nation have worked with might and main to surpass one another in chemical discoveries; and the advantage that we have gained has been largely due to the cooperative spirit generated by our society activities. A nation must be able to stand chemically alone unless it would be subservient, so utterly does present-day civilization depend upon chemistry for a thousand-and-one everyday foods and materials. And it grows more and more apparent that to help one's country to be chemically independent is the profoundest kind of patriotism.

The objective of scientific research today, moreover, is broader than the solution of technological and chemical problems. It takes into its view the responsibility for enlivening the imagination of the masses who will be the chief beneficiaries of these new ways of living.

A true scientist never grows old in his way of thinking. His mind is constantly working to improve his surroundings and to better understand the laws of nature. He expects to live in a changing world.

TRANSMUTATION OF MATTER [1]

By Lord Rutherford, D. Sc., Ll. D., Ph. D., F. R. S.

Toward the close of the nineteenth century, when it seemed certain that the atoms of the elements were unchangeable by the forces then at our command, a discovery was made which has revolutionized our conception of the nature and relations of the elements. I refer to the discovery in 1896 of the radioactivity of the two heaviest elements, uranium and thorium. It was soon made clear that this radioactivity is a sign that the atoms of these elements are undergoing spontaneous transmutation. At any moment, a small fraction of the atoms concerned become unstable and break up with explosive violence, hurling out either a charged atom of helium, known as an α-particle, or a swift electron of light mass called a β-particle. As a result of these explosions, a new radioactive element is formed, and the process of transmutation once started continues through a number of stages. Each of the radioactive elements formed in this way breaks up according to a simple universal law but at very different rates. In a surprisingly short time, these successive transformations were disentangled and more than 30 new types of elements brought to light, while the simple chemical relations between them were soon made clear.

We had thus been given a vision of a new and startling subatomic world where atoms break up spontaneously with an enormous release of energy quite uninfluenced by the most powerful agencies at our disposal. Apart from uranium and thorium and the elements derived from them, only a few other elements showed even a feeble trace of radioactivity. The great majority of our ordinary elements appeared to be permanently stable under ordinary conditions on our earth. Science was then faced with the problem, whether artificial methods could be found to transmute the atoms of the ordinary elements. Before this problem could be attacked with any hope of success, it was necessary to know more of the actual constitution of atoms. This information was provided by the rise of the nuclear theory of

[1] Shortly before his death on October 19, 1937, Lord Rutherford completed the presidential address which he proposed to deliver at the meeting of the Indian Science Congress Association on January 3-9, 1938. The latter part of the address is here reproduced and represents Lord Rutherford's last pronouncement on a subject with which his name will always be associated. Reprinted by permission from Nature, vol. 141, No. 3558, January 8, 1938.

atomic structure, which I first suggested in 1911. The essential controlling feature of all atoms was found to reside in a very minute central nucleus which carried a positive charge and contained most of the mass of the atom. A relation of unexpected simplicity was found to connect the atoms of all the elements. The ordinary properties of an atom are defined by a whole number, which represents the number of units of resultant positive charge carried by the nucleus. This varies from 1 for hydrogen to 92 for the heaviest element uranium, and, with few exceptions, all the intervening numbers correspond to known elements.

On this view of atomic structure it was evident that, to bring about the transmutation of an atom, it was necessary in some way to alter the charge or mass of the nucleus or both together. Since the nucleus of an atom must be held together by very powerful forces of some kind, this could only be effected by bringing a concentrated source of energy of some kind to bear on the individual nucleus. The most energetic projectile available at that time was the swift α-particle spontaneously ejected from radioactive substances. If a large number of α-particles were fired at random at a sheet of matter, it was to be expected that one of them must occasionally approach very closely to the nucleus of any light atom in its path. In such a close encounter, the nucleus must be violently disturbed, and possibly under favorable conditions the α-particle might actually enter the nuclear structure.

This mode of attack upon the nucleus at once proved successful. I found in 1919 that nitrogen could be transformed by bombardment with fast α-particles. The process of transmutation is now clear. Occasionally an α-particle actually enters the nitrogen nucleus and forms with it a new unstable nucleus which instantly breaks up with the emission of a fast proton (hydrogen nucleus) and the formation of a stable isotope of oxygen of mass 17. About a dozen of the light elements were found to be transformed in a similar way. The protons liberated in the nuclear explosions were at first counted by observing the flashes of light (scintillations) produced in phosphorescent zinc sulphide. This method was slow and very trying to the eyes of the observers. Progress, however, became more rapid and definite when electrical methods of counting individual fast particles were developed. These electrical counters, mainly depending on the use of electron tubes for magnifying small currents, have now reached such a stage of perfection that we are able to count automatically individual fast particles like α-particles and protons even though they enter the detecting chamber at a rate as fast as 10,000 per minute. By other special devices, we are in like manner able to count individual β-particles. In this connection, I must not omit to mention that wonderful instrument, the Wilson expansion chamber, which makes visible to us the actual tracks of flying fragments of atoms resulting from an atomic

explosion. These remarkable devices have played an indispensable part in the rapid growth of knowledge during the last few years. It is to be emphasized that progress in scientific discovery is greatly influenced by the development of new technical methods and of new devices for measurement. With the growing complexity of science, the development of special techniques is of ever-increasing importance for the advance of knowledge.

Up to the year 1932, experiments on transmutation were confined to the use of α-particles for bombarding purposes. It became clear that the process of transformation was in most cases complex, since groups of protons with different but characteristic energies were observed when a single element was bombarded. This led to the conception that discrete energy levels existed within a nucleus, and that under some conditions part of the excess energy was sometimes released in the form of a quantum of high-frequency radiation.

The stage was now set for a great advance, and four new discoveries of outstanding importance were made in rapid succession in the period 1931–33. I refer to the discovery of the positive electron by Anderson in 1931, of the neutron by Chadwick in 1932, of artificial radioactivity by M. and Mme. Curie-Joliot in 1933 and of the transmutation of the elements by purely artificial methods first shown by Cockcroft and Walton in 1932.

The discovery of the neutron—that uncharged particle of mass nearly 1—was the result of a close study of the effects produced in the light element beryllium when bombarded by α-particles. It is noteworthy that the proton and neutron, which are now believed to be the essential units with which all atomic nuclei are built up, owe their recognition to a study of the transmutation of matter by α-particles.

Before the discovery of the neutron, it had been perforce assumed that nuclei must in some way be built up of massive protons and light negative electrons. Theories of nuclear structure became much more amenable to calculation when the nucleus was considered to be an aggregate of parts like the proton and neutron which have nearly the same mass. There was no longer any need to assume that either the positive or the negative electron has an independent existence in the nuclear structure. We are still uncertain of the exact relation, if any, between the neutron and the proton. The neutron appears to be slightly more massive than the proton, but it is generally believed, although no definite proof is available, that the proton and neutron within a nucleus are mutually convertible under certain conditions. For example, the change of a proton into a neutron within the nucleus should lead to the appearance of a free positive electron, while conversely the change of a neutron into a proton gives rise to a free negative electron. In this way it appears possible to account for the

observed fact that either positive or negative electrons are emitted by a large group of radioactive elements to which I will now refer.

In the early experiments on transmutation by α-particles, it was supposed that a stable nucleus was always formed after the emission of a fast proton. The investigations of M. and Mme. Curie-Joliot showed that in some cases elements were formed which, while momentarily stable, ultimately broke up slowly, exactly like the natural radioactive bodies. Most of these radioactive bodies formed by artificial methods break up with the expulsion of fast negative electrons, but in a few cases positive electrons are emitted. Since the presence of these radioactive bodies can be easily detected, and their chemical properties readily determined, this new method of attack on the problem of transmutation has proved of great value. Nearly a hundred of these radioactive bodies are now known, produced in a great variety of ways. Some arise from the bombardment by fast α-particles, others by bombardment with protons or deuterons. As Fermi and his colleagues have shown, neutrons, and particularly slow neutrons, are extraordinarily effective in the formation of such radioactive bodies. On account of its absence of charge, the neutron enters freely into the nuclear structure of even the heaviest element, and in many cases causes its transmutation. For example, a number of these radioactive bodies are produced when the two heaviest elements, uranium and thorium, are bombarded by slow neutrons. In the case of uranium, as Hahn and Meitner have shown, the radioactive bodies so formed break up in a succession of stages like the natural radioactive bodies, and give rise to a number of transuranic elements of higher atomic number than uranium (92). These radioactive elements have the chemical properties to be expected from the higher homologues of rhenium, osmium, and iridium of atomic numbers 93, 94, and 95.

These artificial radioactive bodies in general represent unstable varieties of the isotopes of known elements which have a limited life. No doubt such transient radioactive elements are still produced by transmutation in the furnace of our sun, where the thermal motions of the atoms must be very great. These radioactive elements would rapidly disappear as soon as the earth cooled down after separation from the sun. On this view, uranium and thorium are to be regarded as practically the sole survivors in our earth of a large group of radioactive elements, owing to the fact that their time of transformation is long compared with the age of our planet.

It is of interest to note what an important part the α-particle, which is itself a product of transformation of the natural radioactive bodies, has played in the growth of our knowledge of artificial transmutation. It is to be remembered, too, that our main source of neutrons for experimental purposes is provided by the bombardment of beryllium

with α-particles. The amount of radium available in our laboratories is, however, limited, and it was early recognized that if our knowledge of transmutation was to be extended, it was necessary to have a copious supply of fast particles of all kinds for bombarding purposes. It is well known that enormous numbers of protons and deuterons, for example, can be easily produced by the passage of the electric discharge through hydrogen and deuterium (heavy hydrogen). To be effective for transmutation purposes, however, these charged particles must be given a high speed by accelerating them in a strong electric field. This has involved the use of apparatus on an engineering scale to provide voltages as high as 1 million volts or more, and the use of fast pumps to maintain a good vacuum.

A large amount of difficult technical work has been necessary to produce such high D. C. voltages and to find the best methods of applying them to the accelerating system. In Cambridge, these high voltages are produced by multiplying the voltage of a transformer by a system of condensers and rectifiers; in the United States of America by the use of a novel type of electrostatic generator, first developed by Van der Graaf. Professor Lawrence, of the University of California, has devised an ingenious instrument called a "cyclotron" in which the charged particles are automatically accelerated in multiple stages. This involves the use of huge electromagnets and very powerful electric oscillators. By this method he has succeeded in producing streams of fast particles which have energies as high as the α-particle ejected from radioactive substances. Undoubtedly this type of apparatus will prove of great importance in giving us a supply of much faster particles than we can hope to produce by the more direct methods.

It was at first thought that very high potentials of the order of several million volts would be required to obtain particles to study the transmutation of elements. Here, however, the development of the theory of wave-mechanics came to the aid of the experimenter, for Gamow showed that there was a small chance that comparatively slow bombarding particles might enter a nucleus. This theoretical conclusion has been completely verified by experiment. In the case of a light element like lithium, transformation effects can be readily observed with protons of energy as low as 20,000 volts. Of course, the amount of transformation increases rapidly with rise of voltage.

The study of the transmutation of elements by using accelerated protons and deuterons as bombarding particles has given us a wealth of new information. The capture of the proton or deuteron by a nucleus leads in many cases to types of transmutation of unusual interest. For example, the bombardment of the isotope of lithium of mass 7 by protons leads to the formation of a beryllium nucleus of mass 8 with a great excess of energy. This immediately breaks up

into two α-particles shot out in nearly opposite directions. When boron 11 is bombarded by protons, a carbon nucleus of mass 12 is formed which breaks up in most cases into three α-particles. The deuteron is in some respects even more effective than the proton as a transmuting agent. When deuterons are used to bombard a compound of deuterium, previously unknown isotopes of hydrogen and of helium of mass 3 are formed, while fast protons and neutrons are liberated. The bombardment of beryllium by very fast deuterons gives rise to a plentiful supply of neutrons. Lawrence has shown that the bombardment of bismuth by very fast deuterons leads to the production of a radioactive bismuth isotope which is identical with the well-known natural radioactive product radium E. Many artificial radioactive elements can be produced, often in great intensity. For example, the bombardment of common salt by fast deuterons gives rise to a radioactive isotope of sodium. This breaks up with a half period of 15 hours, emitting not only fast β-particles but also γ-rays at least as penetrating as those from radium.

It may well be that in course of time such artificial radioactive elements may prove a useful substitute for radium in therapeutic work. By these methods also, such intense sources of neutrons can be produced that special precautions have to be taken for the safety of the operators of the apparatus.

Sufficient, I think, has been said to illustrate the variety and interest of the transmutations produced by these bombardment methods. It should, however, be pointed out that transmutation in some cases can be effected by transferring energy to a nucleus by means of γ-rays of high quantum energy instead of by a material particle. For example, the deuteron can be broken up into its components, the proton and neutron, by the action of the γ-rays from radium or thorium. As a result of the bombardment of lithium by protons, γ-rays of extraordinarily great quantum energy as high as 17 million volts are strongly emitted. Bothe has recently shown that these high-energy rays are able to transmute a number of atoms, neutrons usually being emitted in the process.

Some simple laws appear to hold in all individual transformations so far examined. Nuclear charge is always conserved, and where heavy particles are emitted, so also is energy when account is taken of the equivalence of mass and energy. Certain difficulties arise with regard to the conservation of energy in cases where light positive and negative electrons are emitted during transmutation, and there is still much discussion on this important question.

The study of the transmutation of matter has been extraordinarily fruitful in results of fundamental importance. In addition to the α-particle, it has disclosed to us the existence of those two building units of nuclei, the proton and neutron. It has greatly widened our

conception of the varieties of atomic nuclei which can exist in Nature. Not only has it led to the discovery of about 100 new radioactive elements, but also of several stable isotopes of known elements, like ^3H, ^3He, ^8Be, which had previously been unsuspected. It has greatly extended our knowledge of the ways in which nuclei can be built up and broken down, and has brought to our attention the extraordinary violence of some of the nuclear explosions which occur. The great majority of our elements have been transmuted by the bombardment method, and in the case of the light elements which have been most carefully studied, a great variety of modes of transmutation has been established.

Rapid progress has been made, but much still remains to be done before we can hope to understand the detailed structure and stability of different forms of atomic nuclei and the origin of the elements. I cannot but reflect on the amazing contrast between my first experiment on the transmutation of nitrogen in the University of Manchester in 1919 and the large-scale experiments on transmutation which are now in progress in many parts of the world. In the one case, imagine an observer in a dark room with very simple apparatus painfully counting with a microscope a few faint scintillations originating from the bombardment of nitrogen by a source of α-particles. Contrast this with the large-scale apparatus now in use for experiments on transmutation in Cambridge. A great hall contains massive and elaborate machinery, rising tier on tier, to give a steady potential of about 2 million volts. Nearby is the tall accelerating column with a power station on top, protected by great corona shields—reminding one of a photograph in the film of Wells's, The Shape of Things to Come. The intense stream of accelerated particles falls on the target in the room below, with thick walls to protect the workers from stray radiation. Here is a band of investigators using complicated electrical devices for counting automatically the multitude of fast particles arising from the transformation of the target element, or photographing with an expansion chamber, automatically controlled, the actual tracks of particles from exploding atoms.

To examine the effect of still faster particles, a cyclotron is installed in another large room. The large electromagnet and accessories are surrounded with great water tanks containing boron in solution to protect the workers from the effect of neutrons released in the apparatus. A power station nearby is needed to provide current to excite the electromagnet and the powerful electric oscillators.

Such a comparison illustrates the remarkable changes in the scale of research that have taken place in certain branches of pure science within the last 20 years. Such a development is inevitable, for, as science progresses, important problems arise which can only be solved by the use of large powers and complicated apparatus, requiring the

attention of a team of research workers. If rapid progress is to be made, such team work is likely to be a feature of the more elaborate researches in the future. Fortunately there is still plenty of scope for the individual research worker in many experiments of a simpler kind.

The science of physics now covers such a vast field that it is impossible for any laboratory to provide up-to-date facilities for research in more than a few of its branches. There is a growing tendency in our research laboratories today to specialize in those particular branches of physics in which they are most interested or specially equipped. Such a division of the field of research amongst a number of universities has certain advantages, provided that this subdivision is not carried too far. In general, the universities should be left free so far as possible to develop their own lines of research and encouraged to train young investigators, for it cannot be doubted that vigorous schools of research in pure science are vital to any nation if it wishes to develop effectively the application of science, whether to agriculture, industry or medicine. Since investigations in modern science are sometimes costly, and often require the use of expensive apparatus and large-scale collaboration, it is obviously essential that adequate funds should be available to the universities to cover the cost of such researches.

SCIENCE AND THE UNOBSERVABLE[1]

By H. Dingle, D. Sc., A. R. C. S.
Professor of Natural Philosophy, Imperial College of Science and Technology, University of London

A new phenomenon has appeared in modern physics: namely, an attempt to apply with rigor the principle that only that which is observable is significant. This is not intended to be a precise statement of the principle. It is at least vague, and perhaps inaccurate, but on that very account it is the most suitable statement with which to begin our discussion. For the principle itself has not yet been clearly isolated from its applications. Unconsciously, progressing more by instinct than by sight, physicists have allowed it to direct their thoughts, but they have not succeeded in giving it clear expression. Consequently it is manifested here in one form and there in another, appearing to some as an outstanding example of scientific arrogance and even absurdity, while to others it has an authority which raises it above common sense and reason alike. The resulting controversy, as may be imagined, has been not without dust and heat, some of which, I fear, must be introduced into the placid atmosphere of this Institution. Let us agree at the beginning that our own considerations shall be at least cool. I will try to mitigate the dustiness, and we will make an unimpassioned attempt to understand the meaning of the principle and to reach a viewpoint from which its validity may be justly appraised.

Let me say at once that the principle is not new. I have no doubt that the Greeks had some words for it. It is certainly to be found disturbing the thoughts of Galileo, Newton, Locke, Hume, Kant, Huxley, Mach, and many others; Huxley, for example, speaks of—

> that exact verbal expression of as much as we know of the fact, and no more, which constitutes a perfect scientific theory.[2]

But on very few occasions in the past has it been more than a pious belief, a doctrine which it has been proper—or only slightly improper—to hold, but which not only has not been allowed to influence the actual prosecution of scientific or philosophical speculation, but has actually been violated therein. It is Einstein who is responsible for the importance which it has today—not because he has stated it

[1] A lecture delivered before the Royal Institution of Great Britain at the Weekly Evening Meeting, Friday, November 26, 1937. Reprinted by permission from the pamphlet of the Royal Institution.

[2] Hume, English men of letters, p. 55, 1879.

more clearly than others, but because he has deliberately brought it into practice and thereby achieved a striking scientific success. Let us hear him speaking of the crux of his theory—the idea of the simultaneity of events occurring at different places.

The concept [of simultaneity] does not exist for the physicist until he has the possibility of discovering whether or not it is fulfilled in an actual case. We thus require a definition of simultaneity such that this definition supplies us with the method by means of which, in the present case, he can decide by experiment whether or not both the lightning strokes occurred simultaneously. As long as this requirement is not satisfied, I allow myself to be deceived as a physicist (and of course the same applies if I am not a physicist), when I imagine that I am able to attach a meaning to the statement of simultaneity. (I would ask the reader not to proceed farther until he is fully convinced on this point).[3]

I think that if this statement had been made at any time in the history of modern science, but had not been applied to the foundations ot physical conceptions, it would have aroused no comment. Einstein would have been regarded as simply saying that if our definition of simultaneity is such that it is essentially impossible to determine whether events are simultaneous or not, then it must be wrong; and everyone would have agreed and turned to more important matters. But he went further. He gave a definition which both accorded with scientific practice and satisfied the requirement he had stated, and then went on to show that certain modifications of our generally accepted notions of space and time must necessarily follow. This put the fat into the fire, and instead of being ignored for saying the obvious, he was railed at for saying the absurd. Philosophers in particular were aroused, and when they realized that a mere empiricist was venturing to challenge their fundamental principles in tones which resounded throughout the world, they proceeded to administer the rebuke which the occasion demanded. Here, for example, is a comment by M. Jacques Maritain, the well-known French Catholic philosopher, on the passage I have quoted (in which, it will be remembered, Einstein asks the reader who is not convinced of his principle to read no farther):

Let us, then, obey our author and read no farther, for this little parenthesis "the same applies if I am not a physicist," is of direct concern to us who have not the honor to be physicists, and it presumes to introduce us into the most fallacious metaphysics. * * * It is a fault so obvious to the eyes of a philosopher to confuse the *meaning* of a concept * * * with the *use* which may be made of the concept in this or that field of study, and more particularly to confuse a thing * * * with the measure which we take of it by our senses and our instruments, that we hesitate to impute such a mistake to anyone, whoever he may be. Everything goes to show, however, that Einstein has made this mistake.[4]

(We may remark in passing that in speaking of measures, Maritain has somewhat confused the issue; measurement is not mentioned by

[3] The theory of relativity, English translation, p. 22, 1920.

[4] Réflexions sur l'Intelligence et sur sa Vie Propre, pp. 205–6, 1926.

Einstein. The point M. Maritain really wishes to make is that the nature of the thing we observe, whether we measure it or not, is independent of our devices for observing it and should, therefore, be independently defined.)

It is not surprising that a physicist and a philosopher should take opposite views of this question, but the matter cannot be disposed of on simple psychological grounds. Here are the diametrically opposed views of two men of science:

> The general point of view [of relativity, writes Prof. C. G. Darwin, a mathematical physicist who needs no introduction to this audience] of questioning the reality of anything unobservable is one of the greatest revolutions in scientific thought that has ever occurred. * * * The great idea which Einstein contributed to scientific philosophy was the principle that if a thing is essentially unobservable then it is not a real thing and our theories must not include it.[5]

This remark has caught the eye of Mr. Albert Eagle, now a mathematician but in his better days an experimental physicist, whose name is known wherever spectroscopy is practiced.

> To me, [says Mr. Eagle] this "great idea" is the most savage example of the application of what is known as the principle of Occam's Razor of which I have heard. * * * Einstein's "great idea" requires us to surrender our commonsense for the sake of an arbitrary dictum of his which he and his followers have raised to a fetish. It is preposterous, and to my way of thinking is so inherently idiotic that I cannot understand anyone wasting his breath in giving utterance to such a view. If I had first heard this opinion uttered at a scientific meeting by some scientific nonentity I should have longed to have got up and said that in my opinion such a view was simply a bit of perverse imbecility.[6]

And finally, here is the attitude of another philosopher, Rudolf Carnap—perhaps the leading exponent of the most active of modern schools of philosophy, the so-called "logical positivism." Carnap, the philosopher, not only accepts the principle; he uses it to reduce to nonsense those branches of his own subject known as metaphysics and ethics.

> I will call *metaphysical*, [he writes] all those propositions which claim to present knowledge about something which is over and above all experience. * * * Metaphysicians * * * are compelled to cut all connection between their propositions and experience; and precisely by this procedure they deprive them of any sense.[7]

In these days, when politeness in controversy, so desirable and proper if directed to the disputants, is so often improperly extended to their ideas, so that few dare speak disrespectfully even of the equator, there is something refreshing in the forthright character of these remarks. And not only are they refreshing; they are highly significant also. When men who are neither fools nor liars agree that a certain idea is either the greatest discovery of a generation or

---

[5] The new conceptions of matter, pp. 23, 81, 1931.
[6] The philosophy of religion versus the philosophy of science, pp. 169-70 (1935).
[7] Philosophy and logical syntax, pp. 15, 17-18, 1935.

114728—39——15

the silliest nonsense imaginable, but cannot agree as to which it is, it is clear that there is more than a difference of opinion; there must be some defect of understanding also. Intelligent men do not thus differ about that which they comprehend equally. It, therefore, becomes a matter of importance to state this principle precisely, so that we shall at least know what we are doing when we bless or curse it. And in seeking to assess its value, we must avoid the error of ascribing greater or less weight to the opinion of a physicist than to that of another. Einstein is perfectly right in saying that if this principle holds for him as a physicist, it holds for him also if he is not a physicist; and M. Maritain offers him a license which he cannot accept when he allows him to apply the principle in physics but not outside. If we talk nonsense, and plead in extenuation that we are only talking as physicists, we fall short of the ideal of rational speech, distinguished precedent notwithstanding. The question must be considered on general rational grounds: are we to admit the unobservable into our scheme of things or are we not? We must give an answer which is independent of the particular scheme which we want to uphold.

Let me for a moment adopt the legal method, and state the case for each side independently, as an advocate might state it. Take first the case for the principle. It is necessary, say its supporters, as a safeguard against irresponsible invention. If we allow that an entity might exist and be significant to thought, although it is essentially unobservable, what is there to prevent us from postulating any number of such entities and invoking them to remove any difficulty that might arise? Suppose, for instance, I assert that there is a binkum sitting on the table in front of me, and that this tremendous fact, rightly understood, is the final, completely satisfying solution of the problem of evil. If you reject the principle in question, you have no grounds for denying the statement. You may say that you cannot detect my binkum, but I reply that of course you cannot, because he is unobservable. If you want to know how his existence solves the problem of evil, I say that it is its nature to do so, and the definition of him, according to your own contention, is quite independent of any means you adopt to investigate him. If you ask, "What is a binkum, anyway?", I reply that that is immediately evident; I cannot put it into words, but everyone knows what a binkum is. If you retort that you do not know, I shrug my shoulders and say that you must be speaking as a physicist.

Stupid as this example sounds, it contains a precise parallel to the case of simultaneity. M. Maritain and those who agree with him claim that the simultaneity of spatially separated events is something independent of our means of observing it. When asked what it is, they claim that its nature is immediately evident and that everyone

knows it. But Einstein says he does not know it, and Einstein is an honorable man. And the only reply is that Einstein and his followers must be speaking as physicists.

We can now press home the point. We agree, let me assume, that science and philosophy are better without the binkum; how, then, can we exclude him? Only, says Counsel for the defence of the principle, by refusing to grant existence to anything that is essentially unobservable. Our only clue to reality is observation in one form or another. And if we admit that, we must go further. Not only must we deny existence to the unobservable: by the same token we are forced also to deny any unobservable property to an existent thing, otherwise we again open the door to the same abuses. And that means that everything whose existence we acknowledge must be definable ultimately in terms of observation—that for everything that we assert about it we must have, in the last resort, some observable evidence. The character of the thing may, of course, be very different from the character of the observation; a star, for instance, may be a dazzlingly bright globe of gas millions of miles in diameter, whereas we observe only a faint pinpoint of light. But there must be a logical passage from every detail we assert about the star to the observation of the pinpoint or other observations of cognate character. If there is the slightest relaxation of this requirement, in comes the binkum with passport signed and sealed.

The case seems established, but we must hear Counsel for the other side. His argument is a *reductio ad absurdum*. Certainly we do not want the binkum, he says, but your device for keeping him out is both presumptuous and absurd; you are throwing out the baby with the bath-water. Consider for a moment what your principle implies. It asserts that there is nothing in the universe except what you can observe—nothing in the physical world beyond the reach of your senses. Suppose we were blind, like the men in Mr. Wells's country; then, according to your principle, we ought to act as they did, and deny existence to the merely visible. How do you know that the universe does not contain things apprehensible only by senses which you do not possess, which perhaps you have lost in the course of evolution or have not yet acquired? Moreover, what about the past? You cannot observe that, for it has gone; therefore, you say, it has no meaning, it must not come into our description of reality. No flower has been born to blush unseen; no feet trod the earth before the beginning of living memory. Such nonsense necessarily follows if your principle is granted. Exclude your binkum by all means—we hold no brief for him; but find some sensible way of doing it, without assuming potential omniscience.

The problem, I think, is now set clearly before us. If we admit the unobservable, there is no check on empty speculation; if we reject the

unobservable, we confine the universe within the bounds of human potentialities and make nonsense of history. What are we to do?

It is evident that we must begin by examining the word "unobservable." Both sides wish to exclude the binkum; both wish to allow the universe a richer content than we can at present perceive. The "unobservable" that is to be proscribed must therefore include the obviously idle fancies but exclude the legitimately transcendental, and we must define it so that it does so inevitably, without special pleading. I need scarcely add that we must distinguish between "unobservable" and "unobserved"—between what we cannot possibly observe and what we have not in fact observed. This needs no elaboration; we agree that an entity is not to be rejected merely because we have not observed it. But what do we mean by "possibly" observable?

There are reasons of various kinds why we may be prevented from observing a thing, but I think they can all be summarized under four headings. First of all, there is what I will call the practically unobservable—i. e., that which is unobservable because of the practical difficulties of observing it. The far side of the moon affords an example. That region is unobservable because we have not solved the problem of interplanetary travel, or succeeded in observing the moon reflected in Mars, or learnt so much about the properties of matter that we are able to deduce from observations of the near side of the moon what the configuration of the far side must be, or performed some other feat of practical ingenuity. It is conceivable that in time this disability will be removed, so that practical unobservability may be merely a temporary characteristic.

Secondly, there is the humanly unobservable; by which I mean the unobservable which is so because we do not possess the necessary faculties for observing it. I cannot, of course, by the nature of the case, give examples of this, but I can give analogies. A great deal of the universe would be humanly unobservable if we had no sense of sight; and to the musically insensitive the significance of a great composer may be said to be humanly unobservable. If, then, there is in the universe some existence which no creature has the faculty of apprehending, that existence is humanly unobservable.

Thirdly, there is what I will call the physically unobservable. A thing may be said to be physically unobservable when we have the faculty for observing it if nature will cooperate, but nature gives that faculty no opportunity for exercise. Thus, if somewhere in space there occurred an event from which no signal—light ray or sound wave or anything else—proceeded to other places, and if there were repulsive forces which prevented us from ever reaching the place of occurrence, that event would be physically unobservable. We have eyes to see it, and hands to touch the bodies concerned in it, but we cannot use them for that purpose. An example important in physical

history is the possibility of observing absolute motion. We have, in the Michelson-Morley experiment and similar devices, instruments which are able to detect absolute motion if nature will provide them with the necessary messengers, but this she fails to do. No matter how we may be changing our motion with respect to other bodies, our absolute motion always appears to be nonexistent. (I am assuming, without prejudice, for the sake of illustration, that Prof. Dayton Miller's experiments do not contradict this statement.)

Lastly, there is the logically unobservable; namely, those things which we cannot claim to have observed without breaking the laws of reason. I doubt if this class is actual, since logic and observation are essentially independent, but, as we shall see, it must be included because a great deal has been written about it. An example might be the observation of an object both larger and smaller than a given object; but I give this example with some hesitation because geometers have an uncanny knack of inventing spaces in which such relations might not be incompatible. Be that as it may, however, if we grant a certain minimum of common agreement—such as the acceptance of Euclidean geometry in the present instance—logical unobservability becomes an intelligible notion, and we will accept it as a candidate for inclusion in our principle.

Now this classification may be simplified; for, whatever may be the ultimate truth of the matter, it is not necessary for our purpose to put the humanly and the physically unobservable in separate classes. I will, therefore, group them together and call them jointly the physically unobservable. The justification for this is that we cannot tell, in any given case, with which class we are dealing. If, for example, a certain substance appears tasteless to everyone (i. e., its taste is unobservable), it is impossible to say whether that is because it has a taste which our senses are not keen enough to detect, or because it has no taste to be detected. There may be a distinction between the two cases, but if so it is beyond our apprehension. But now our principle is essentially one which, if valid, must be used; it is not a creed which we are merely called upon to state and may then ignore. The humanly and the physically unobservable, then, become one class so far as our problem is concerned, for if in practice we reject one, we automatically reject the other also.

We have, then, three classes of unobservables, and I think the distinction between them may be expressed most simply in the following way. Let us suppose that we have discovered all the means of observation that exist in the universe, and know all their properties completely. We might then be able to imagine other means of observation which do not exist. Anything which would be observable by such imaginary means, but not by the existing means, would be physically unobservable. Anything which would be

unobservable by any means, existing or imaginable, would be logically unobservable. Anything which would be observable by the existing means if we were also omnipotent, but which actually is unobservable because we cannot make full use of the means of observation which exist, would be practically unobservable.

We can now proceed a stage further. We have just seen that, for our purpose, the humanly and the physically unobservable become one class because we cannot at present distinguish between them. Let us look, then, at our latest classification, to make sure that the three types of unobservability we have now reached are immediately distinguishable. It is fairly evident, I think, that they are, if we grant the initial supposition that we have discovered all existing means of observation. For brevity, I will call that the assumption of omniscience, and you will understand that by that word I do not mean knowledge of everything that exists or that can be observed, but complete knowledge of the existence and properties of every means by which observation is possible. For example, omniscience implies complete knowledge of all the properties of light, but not necessarily of all objects which are visible. Now, clearly, this assumption of omniscience is open to challenge, and it is, therefore, necessary to see how our classification looks if it is removed. Can we then still recognize the three classes as distinct?

There is no difficulty, I think, with the logically unobservable. Since this class consists of things which are not even imaginably observable, it makes no difference how much we know of possible observability. There can be no possible means of observation that is not imaginable. There may be unimagined means, of course. We may make discoveries that take us by surprise, but those discoveries must have been imaginable, or we could not have apprehended them at all. Whatever we know of observability, then, does not affect our potentialities of observation, so that the logically unobservable is a definitely distinguishable class, independently of our assumption of omniscience.

The case is different, however, with the practically and the physically unobservable, for these classes cannot be distinguished if we do not regard ourselves as omniscient. We said that the far side of the moon was practically unobservable, but if we are not omniscient, how do we know that when we have overcome what seem to be the present difficulties; when we have made vessels with adequate air and food supply, and vehicles that we can drive accurately and swiftly enough to take us unharmed to the moon during a week-end—how do we know that nature will not then face us with some unexpected difficulty like that which she kept in store for our efforts to determine our motion through the ether? If she does, and persists in doing the same kind of thing, we shall have to call the far side of the moon

physically and not only practically unobservable. And, on the other hand, when we say that absolute motion is physically unobservable, we are again assuming omniscience. We cannot observe such motion by optical, acoustical, electromagnetic or any other means within our present knowledge, but, without the assumption, who can say that there is not some undiscovered physical medium through which it may be detected? If there is, absolute motion is merely practically, and not physically, unobservable. It is clear, I think, that unless we are omniscient the two classes are indistinguishable.

Our analysis of unobservability, then, finally brings us to this. If we assume that we are omniscient we can distinguish three classes—the practically, the physically, and the logically unobservable. If we do not assume that we are omniscient we can distinguish only two classes—the actually and the logically unobservable, let us call them. The importance of this conclusion for our purpose is this. We are going to look at the actual practice of physics, to see what kinds of unobservable are excluded and what kinds are not. If we find that a distinction is made between the practically and the physically unobservable, then we know that physics is assuming omniscience; but if no distinction is made, then there is no such assumption.

Let me state the result at once, afterward giving examples to justify the statement before proceeding to consider the validity of the principle we are considering in its definite form. The practice of physics is to recognize three classes—the practically, the physically, and the logically unobservable. Of these it excludes the physically and the logically unobservable from its considerations, and aims at describing the universe in terms of the observable and the merely practically unobservable only. It thus assumes omniscience, in the sense in which I have defined the word.

It will not take us long to see that physics includes the practically and excludes the logically unobservable. No physicist denies that the moon has a far side in the same sense as it has a near side. We assume without question that the earth has an interior, that there are stars outside the range of our telescopes, and regions beyond the obscuring clouds of the Milky Way. All these things could be observed if known means of observation have precisely the properties we believe them to have and we had the skill to make full use of them. Hence the practically unobservable is admitted to physical theory.

We may deal equally summarily with the logically unobservable. Nasty things have been said about the reasoning of some modern physicists when they step outside the bounds of their equations, but I do not think the bare, unadorned physical theories themselves have been called illogical, either with pride or with shame. If, then, the structure of physical theory allows ontological significance to anything which is logically unobservable, it does so through an oversight,

and theory will undoubtedly be reformed as soon as the oversight is discovered. We may say, therefore, that the practice of physics is to reject the logically unobservable.

But now, the unobservables whose rejection has caused all the controversy belong to neither of these classes. Let us fix our attention on the example of absolute simultaneity, with which the discussion began. This, as we know, is rejected, and that cannot be because it is practically unobservable, for physics reeks of the practically unobservable. Nor is absolute simultaneity logically unobservable. We can conceive that the universe might be such that two events at different places might occur at the same time in an absolute sense, and that this fact might be observable. I should mention, however, that this has been denied, so I will presently show in more detail why absolute simultaneity cannot be regarded as logically unobservable, but for the moment I will take it to be established in order not to interrupt the main course of the argument. We cannot, then, escape from the conclusion that absolute simultaneity belongs to a third class of unobservables, which we shall see is what I have called the class of physically unobservables; and the recognition of this class commits physics to the assumption of omniscience.

To see that absolute simultaneity is physically unobservable, let us look at the obstacle that prevents us from observing it. Why can we not say, in an absolute sense, that two events occurring at different places are simultaneous? It comes down to the fact that we can know of the events only through some agency which travels from them to us and takes time to do so. Consider two events—say, the impact of a meteorite on a lunar crater and the outbreak of a new star in the Milky Way. We know of these events when we see them (or their effects) but we do not see them at the moments at which they occur because the light which makes them visible takes time to travel; and although, perhaps, we observe them on the same evening, one may have occurred 100 years after the other. We can, of course, allow for this by calculating how long the light has taken to travel, but when we do so, according to standard methods and principles, we find that the results depend on the way in which we happen to be moving with respect to the bodies on which the events occurred. Furthermore, we cannot distinguish in an absolute sense between one state of motion and another; so far as we can determine, all states are equally valid or equally invalid. Hence, we do not know what allowance to make for the time of travel of the light, and, therefore, cannot determine absolutely whether the events were simultaneous or not. The word "absolutely" is important. We can determine quite definitely if the events are simultaneous if we assume that we are at rest or that we are moving in any definitely specified way; but what we cannot do is to justify our assumption if it is challenged.

The unobservability of absolute simultaneity, then, depends on the fact that we cannot determine unambiguously how long light takes to inform us of an event; or, more generally, how long after an event it is possible for us to know of it. This ignorance, of course, would not be necessary if we could know of an event immediately it occurred—if, this is to say, we could observe it by some messenger which traveled at an infinite speed. This is not pure fancy. Before the time of Römer, in the seventeenth century, it was believed that light might travel at an infinite speed, and before the theory of relativity arose, it was believed that gravitational action was transmitted instantaneously. It is not uncommon, too, to imagine that there might be instantaneous telepathic communication. We can at least, then, conceive that an instantaneous messenger might exist, and therefore absolute simultaneity is not logically unobservable. It is unobservable simply and solely because, so far as our present survey of the universe has gone, there is no evidence that it is possible to learn of a distant event at the moment at which it occurs. In other words, absolute simultaneity is physically unobservable.

It is important to emphasize this because, as I remarked just now, it has been claimed that absolute simultaneity is rejected because it is logically unobservable, and this claim has been made the basis of the philosophy of the logical positivists. Let us hear the late Prof. Moritz Schlick, one of the foremost and most able of the founders of this school of thought. He maintains that there are only two significant classes of unobservables, corresponding to what I have called the "actually" and the "logically" unobservable.

> The distinction between impossibility of fact and impossibility of principle, is absolute, without the slightest ambiguity; it is not of such and such a degree; it is essential.[8]

He then cites Einstein's rejection of absolute simultaneity as an example of the rejection of the logically unobservable, the "impossibility of principle." He makes it quite clear that he does not distinguish between the physically and the practically unobservable; they are all included in the "impossibility of fact."

> The statement, "There are mountains 3,000 meters high on the far side of the moon," is perfectly sensible, although our present technical skill is insufficient to assure us of its truth or falsity. It would still be sensible if it were unquestionably established scientifically that man would never reach the far side of the moon by any means. The verification remains *conceivable*; we are able to express what it would be necessary to do to decide the question, what it would be necessary to experience; verification is *logically* possible, and that is all that matters.

I hope I have made it clear that if the conceivability of verification is all that matters, absolute simultaneity is verifiable, and, therefore, not logically unobservable. We can conceive of the possibility of

[8] Erkenntnis. French translation in Actualités Scientifiques et Industrielles, No. 152, p. 25 (1934).

learning of an event at the moment of its occurrence. If, then, two separated events occur at the same instant, it is conceivable that we should observe them at the same instant. Now no one has denied that simultaneity of observation is significant; it is only simultaneity of occurrence of the events that is in question. Hence, since simultaneity of occurrence is conceivably deducible from simultaneity of observation, it also would be significant if the logically unobservable alone were excluded.

We can now, at last, give a rigorous form to the principle which is the subject of our inquiry. It is this: that only that which would be observable if we were able to use known means of observation to the known limits of their possibilities, is significant. Our description of the universe must describe nothing else, must imply the existence of nothing else, must imply the possible existence of nothing else. If we do not accept this principle, we must reject relativity and a considerable part of the quantum theory as worthless illusion.

The next step, clearly, is to examine the credentials of this principle on general rational grounds, but before doing so I want to give another example of its application, in order to emphasize the fact that it is not an unimportant appendage of physical theory, but the very mainspring of the most prominent modern developments. Heisenberg's uncertainty principle is perhaps the best-known example, but I will not deal with that because it is too closely bound up with other factors which there is no time to consider. I choose instead an idea which stresses the point still more forcibly because it is not generally regarded as exemplifying the principle in question, but is attacked or defended on quite other grounds. The principle has taken root so deep in the minds of physicists that they employ it unconsciously, and justify their action by arguments which appear to others either incomprehensible or absurd. I am speaking of the idea that the physical universe is finite but boundless. This idea can be made intelligible in 5 minutes when presented as an example of the principle of rejection of the physically unobservable, and I believe that those who accept it are convinced of its rationality because they have already accepted that principle. They are not aware of this source of their conviction, however, and therefore have to justify their belief by saying that space is "curved," that it "bends back on itself"—an "idea" which I do not think it is humanly possible to grasp except as a metaphor of the kind one meets with in the "metaphysical" poetry of the seventeenth century. Whether or not that psychological diagnosis is accurate, however, is unimportant; the main point is to see that, in terms of our principle, the idea that space is finite and boundless is intelligible without calling on such unimaginable notions as curvature.

The idea is that if we were free to move about in space eternally, wherever nature led, we would always find ourselves apparently in the midst of a collection of stars or nebulae, though we could not forever be meeting new objects, but would have to endure the tedium of seeing the old familiar faces endlessly, without relief. Like our former example, this idea, in its modern form, originated with Einstein; let us see how it has impressed his contemporaries. Sir Arthur Eddington, who thinks very highly of it, writes thus:

Einstein made a slight amendment to his law to meet certain difficulties that he encountered in his theory. There was just one place where the theory did not seem to work properly, and that was—infinity. I think Einstein showed his greatness in the simple and drastic way in which he disposed of difficulties at infinity. He abolished infinity. He slightly altered his equations so as to make space at great distances bend round until it closed up.[9]

On the other hand, here is the stimulating Mr. Eagle again.

I fancy Einstein is honestly a bit tired and weary of "curved space," and is probably a bit sorry he ever suggested such a thing. But he did not know with what zeal other people would take it up and make a world-wide fuss about it. In pre-Einsteinian days if people had been told that an author's theme in his book had been that external reality only possessed three spatial dimensions, and that therefore to talk of "curved three dimensional space" was pure nonsense, they would have replied that they thought only lunatics thought otherwise. Now this conception is widely regarded in many circles as a "probably may be true" one. This, to me, seems the measure to which both the scientific world and the general public have been bluffed by the theory. Future scientific historians will probably regard the theory as a befitting product of a mad age in the world's history.[10]

Prof. E. A. Milne is scarcely less contemptuous of this manifestation of Einstein's greatness.

It is not necessary to employ the vague, ill-understood, probably meaningless concept of closed, finite expanding space.[11]

Well, the symptoms are familiar. Again we have the alternative estimates of supreme greatness and supreme folly, and we might suspect that the same misunderstanding is at the bottom of the trouble—as, in fact, it is. Let us begin with a finite collection of stars (or nebulae) in a space which we suppose extends to infinity in all directions (fig. 1); we are somewhere in the midst of the collection—say at A. Now suppose we try to get outside into the empty spaces. We cannot, because the gravitation of the system keeps all material bodies inside; the faster we move, the greater is the attraction, and we find ourselves following some such path as that shown in the diagram. It is the same with light; that also is drawn back, and cannot illuminate whatever external objects there may be. In fact

[9] The expanding universe, p. 21, 1933.

[10] The philosophy of religion versus the philosophy of science, pp. 219–20.

[11] Zeits. f. Astrophysik, vol. 6, p. 83, 1933.

no physical existence that we know of can escape. All that is perfectly conceivable; and I am not, of course, concerned with whether it is *true* or not, any more than I was concerned earlier with the truth of the statement that the velocity of light is finite; that is a matter for experiment, and my purpose is served if I can show that the idea of finite boundlessness could be true without violation of ordinary notions.

FIGURE 1.—Model of finite universe.
From "Through Science to Philosophy." By H. Dingle.
[*Courtesy of the Clarendon Press, Oxford*]

We picture, then, a finite universe from which we cannot escape. The next point is that it is impossible for us to know whether we are at its center or its boundary; in either case we appear to be surrounded by stars on all sides. Obviously an observer at the center (or at A) sees stars all round, but so does an observer at B, for the light of the stars inside is bent, so that he sees then whichever way he looks. The light of a star at S, for example, is bent so that the star appears to be at S^1. This is a very ordinary phenomenon, exemplified every time we look at a mirror; an object appears in the direction of the

light that enters our eye, and not necessarily where it actually is. We are, therefore, not only confined within the universe, but necessarily without the possibility of the experience of being at the boundary; however we move, and wherever we go, we must always see the same kind of thing—stars more or less uniformly distributed all round.

All that is of the nature of simple, traditional physics; now comes the crucial point. Since the region outside the system is physically inaccessible and unobservable, and the experience of being at its frontier is physically unattainable so that it is never possible for us to know whether we are there or not, we leave these things outside our description of the universe. We give the name "space" to the volume which contains what we can observe, and describe it simply according to our experience as both finite and boundless. We can still, of course, conceive that there is an infinite region outside (wherever "outside" may be), but that is merely another way of saying that the region is not logically unobservable. The rejection of infinite space is, in fact, precisely similar to the rejection of absolute simultaneity: it represents an economy of ideas—we are to introduce no conceptions which are not necessary for the description of the physically observable.

It may be worth while to point out that this account of finite boundlessness differs from the statement that space is curved in the fact that it says nothing about any intrinsic property of space. There is no need to try to think of emptiness with a curvature; we have simply to think of possible experience, and keep within its bounds. Of course, for mathematical purposes the conception of curvature is useful because it allows us to employ the technique of Riemannian geometry to solve particular problems, and for the mathematician it may have some esthetic value, as the poetry of Mr. T. S. Eliot is said to have for those "in the know." But for the purpose of understanding it is worse than superfluous; it is definitely misleading.

What, now, of the validity of this principle, which has taken charge of physics and threatens to direct all future philosophical thought? Let me repeat the principle; it says that nothing which is logically or physically unobservable is significant. This statement must be appraised on prescientific, general rational grounds, and we can best approach the task by returning to the rival arguments set out earlier and considering them in the light of our rigorous statement.

The essence of the argument for the principle is that it is needed to prevent arbitrary invention of existences or arbitrary dogmas about them; and it meets this requirement by saying, in effect, that everything that exists is observable by known means. The argument against the principle is that we have no right to assume omniscience; that although it may be granted that the logically unobservable cannot exist, it is presumptuous to say the same of the physically unob-

servable. And, as an example of the absurdity to which the principle leads us, it was pointed out that it would require us to deny the reality of all that is past.

Now, before coming to the main issue, it may be well to point out that this example does not hold good. The past is not physically unobservable, but only practically so. Every event in the past interacted with the rest of the universe, and the effects of the interaction persist in one form or another; it could, therefore, in principle be deduced from an analysis of those effects, just as the course of certain past events can be observed from a cinematograph film. True, photography is a specially arranged type of interaction, the results of which can be analyzed into a reproduction of the original events with relative ease, but that is merely a practical difference. Since radiation is going out from every event at every instant, and radiation, as energy, is indestructible, there always exists the physical possibility of tracing it back from whatever form it may have assumed to its original character, and so recovering the past. Before concluding that the principle is inherently absurd, therefore, it is necessary to examine it with some care, for it leaves the possibility of a richer universe than might at first be suspected.

But making all due allowance for that, the criticism remains that the principle does categorically deny existence to whatever cannot be physically observed, and that this implies an unwarrantable assumption of omniscience. We are, therefore, in this dilemma. If we deny the principle, we have no check on idle invention; it may be that all that we know, and have taken such pains to find out, is trivial, while the great, important facts of the universe are not even suspected and are unattainable—at least with our present human faculties and knowledge, and perhaps altogether. On the other hand, if we accept the principle, we close the door to all experience outside that which our present knowledge allows. Our mental, like our physical, universe becomes finite, and all that the future provides scope for is more ingenious manipulation of things we already know. And let me repeat that this dilemma is not a domestic affair for physicists. In physics it concerns at present only existences observable by sense perception, but, clearly, it is equally relevant, in the appropriate forms, to all spheres of thought in which we regard ourselves as apprehending some independent existence by means of human faculties.

This last sentence, I think, gives the clue to the solution of the problem: "All spheres of thought in which we regard ourselves as apprehending some independent existence by means of human faculties." That is the attitude which I have assumed throughout this discussion—the attitude of naive realism in which we picture an objective universe existing independently of our thought of it and our examination of it. It is the attitude which we always assume in

everyday intercourse and in most scientific discussions also. We regard scientific research as an exploration of this independent universe, an attempt to discover what it contains and to understand the preestablished relation of one part with another. It is this conception of science or philosophy that makes possible the dilemma by which we are faced. If the universe exists independently of our experience of it, then clearly it is presumption on our part to deny that it can contain anything inaccessible to experience. And, on the other hand, if we abstain from this presumption we make all inquiry a mockery, for we have no guarantee that anything that we may discover is more than a triviality, an insignificant part of a universe whose essential elements are eternally unknowable. We may, it is true, make a verbal escape from the dilemma by saying that, although the universe may be mainly unknowable, we proceed by an act of faith that we are given faculties capable of apprehending it completely; but such an act of faith is both logically and practically indistinguishable from the assumption of omniscience—it is simply arrogance wearing the cloak of humility.

But suppose we take the idealistic view, regarding our experience, our observations, as the primary data, and the universe as a mental construct formed to give rational coherence to those observations. The whole matter then appears in a different light, in which the dilemma is no longer seen. The statement that nothing which is logically or physically unobservable is significant is simply a statement of our aim as scientists or philosophers; it means that we confine ourselves to our purpose of deducing a universe from our observations and do not allow our fancies to intervene. There is no assumption of omniscience because there is no independent universe to know, and the arrogance disappears because we make no claim to know all the possibilities of observation. We set no limit to the possibilities of experience; we simply refuse to assert anything for which we have no (direct or indirect) justification in experience, and as observation grows the universe grows also. The objection to the principle, therefore, vanishes completely, from the idealistic point of view.

On the other hand, the objection to denying the principle by no means vanishes. If we do not exclude the physically unobservable from our description of the universe, we still have no grounds for not admitting the binkum and so reducing philosophy to a farce. When M. Maritain claims that a thing is independent of our observation of it, he immediately makes it impossible for us to know that we are saying anything of the least importance about it, no matter whether we adopt the realistic or the idealistic viewpoint. If we are realists, the thing may be essentially beyond apprehension; and, if we are idealists, we may form it equally legitimately from observation or from fancy.

The position, then, is this. If we take the realistic view, we are left

with an unresolved dilemma, but if we take the idealistic view, the principle becomes simply a statement of the object at which science has aimed throughout its history. It is not my purpose to comment on the age-old problem of idealism versus realism; I am concerned only with the attitude implied in modern scientific developments. And the point I want to emphasize as clearly and unmistakably as possible is that anyone who regards the recent trend of physics in general, and the theory of relativity in particular, as legitimate science or philosophy or intellectual activity bearing whatever name may be thought honorable, must either be an idealist or presume that he is omniscient. I do not wish in this place to plead the cause of either of the alternatives open to the humble. I am not anxious to cry "Vote for realism, and down with relativity!" or "Support idealism and relativity, and throw realism to the dogs!" That is a matter for personal predilection, but it is a matter for pure reason to show that those are the only alternatives open to anyone who is not prepared to assume that he is omniscient.

The striking divergence of opinion with which we opened can now, I think, be understood. Those who, like M. Maritain and Mr. Eagle, see the principle in question as an example of presumption arising from ignorance, are realists—by which I mean that they instinctively think as realists, whether or not they would accept the title. On the other hand, those physicists and philosophers who accept the principle are, by the same criterion, idealists, though most of them speak our ordinary, everyday language which has accommodated itself to the realistic outlook. In terms of that language their utterances necessarily appear arrogant; what they apprehend instinctively as the wisdom of a self-imposed discipline is clothed in sentences which suggest to the realist the idea of arbitrary dogma. The divergence, arising as a difference of philosophical attitude, is accentuated by the necessity of expressing idealistic principles in realistic terms.

Let me, in conclusion, recapitulate the argument. The practice of modern physics is found on examination to imply that nothing must be included in our description of the universe that would not be observable if we had full control of all known means of observation. If we adopt the realistic view that the universe exists independently of our observation of it, this implies that the means of observation which we already know are sufficient to reveal everything that exists. We must in that case either make this assumption, for which we have no warrant, or else reject the recent developments of physics. If we choose the second alternative, we are left without any assurance that we can know anything of importance about what exists outside us. On the other hand, if we adopt the idealistic view that the universe is constructed mentally by logical inference from experience, we see the implication of modern physics as simply the traditional thesis of science that the data we choose shall be pure experience, unalloyed with fancy or arbitrary dogma.

SOME ASPECTS OF NUCLEAR PHYSICS OF POSSIBLE INTEREST IN BIOLOGICAL WORK [1]

By L. A. DuBridge
University of Rochester, Rochester, New York

[With two plates]

In selecting a title for this paper I have endeavored to choose one which would create no illusions as to its purpose or content. It is my purpose only to review (in a very elementary way) some of the aspects of nuclear physics which give promise of providing useful tools in biological research. I shall attempt to indicate a few of the types of problems to which these tools may be applied. I am not reporting any research which has been carried on in this field. I cannot claim originality for any of the suggestions I am going to make concerning biological problems, since they are all either more or less obvious or else have been proposed by various workers interested in this field.[2] Note that these are only suggestions as to possible problems to which these new tools may be applied, not predictions of any definite results which may be obtained. It is as difficult to make predictions in this field now as it would have been 35 years ago to predict the biological applications of X-rays and radioactivity.

Nevertheless, despite these cautious remarks, it is my own conviction, inspired by the conviction of many others better able to judge, that the discoveries of the last 5 years in nuclear physics are almost certain to be of far reaching importance in biology. They will greatly facilitate experimental work now going on in certain fields, and they will doubtless uncover new problems not now suspected or not open to attack by present experimental methods. Many feel that a new era in biological technique is now at hand. If this be true no further apologies need be offered for any attempt to acquaint biologists with the nature of the new tools for research which they are likely soon to be using.

We will do well to begin the discussion by listing some of the most important advances in nuclear physics in recent years.

[1] Presented at the Symposium on Biophysics, Philadelphia, Pa., November 4, 5, and 6, 1937. Reprinted by permission from the Journal of Applied Physics, vol. 9, No. 3, March 1938.

[2] I am particularly indebted to Prof. E. O. Lawrence, with whom these problems have been discussed in some detail.

114728—39——16

1. The discovery, measurement, and separation of isotopes of the chemical elements (Aston, Bainbridge, Urey, et al.).

2. The development of machines for accelerating charged particles to very high energies (1 to 8 million electron volts).

(a) Transformer-condenser methods (Cockcroft and Walton, Lauritsen, et al.).

(b) Electrostatic generator (Van de Graaff, Tuve).

(c) The cyclotron (Lawrence, Livingston, and Cooksey).

(d) Linear accelerators, resonance transformers, etc.

3. The transmutation of elements:

(a) By natural alpha-particles (Rutherford, 1919).

(b) By artificially accelerated protons (Cockcroft and Walton, 1932).

(c) By deuterons (Lawrence, 1933).

(d) By neutrons (Feather, 1932).

4. Discovery of the positron (Anderson, 1932).

5. Discovery of the neutron (Chadwick, 1932).

6. Discovery of induced radioactivity (Curie-Joliot, 1934).

We shall pass over the field of isotopes without discussion. The heavy isotopes of hydrogen, carbon, oxygen, etc., are of great importance to nuclear physics and to biology but their use in the latter field is largely a problem of chemistry—and I shall leave it to the chemists to discuss.

Similarly, it will not be profitable in this discussion to describe in detail the experimental techniques which have been developed for producing high energy particles. It is the development of these techniques, of course, which has made possible all the other advances: without them it would not be possible even to discuss in a practical way the possible biological applications of nuclear physics. In fact, there would be very little nuclear physics. The time may not be far distant when a cyclotron or a Van de Graaff generator will be standard equipment in large biological and medical research centers. But our chief interest in this symposium is what these machines will do rather than how they work. The principal thing they will do is to produce transmutations of elements, and the products of these transmutations are the things which biologists may find useful. I should also mention, however, that resonance transformers and Van de Graaff machines are also suitable, and are even now in use in several medical centers, for the production of million-volt X-rays. Still higher voltages can be produced as soon as they are required, but it will be best to understand something of the effects of 1-million volt X-rays before 2-million volt machines are built. These machines bring X-ray energies right into the realm of gamma-rays, with available intensities which are thousands of times greater than those attainable from natural radioactive sources.

The great importance of extending radiological investigations into this region is sufficiently obvious. There is but one interesting point worth mentioning. One advantage usually ascribed to high energy X-rays is their greater penetrating power. However, this increase of

penetrating power with increasing energy (decreasing wave length) does not continue indefinitely. Above about 2.5 million volts (Mv) the penetrating power of X-rays in lead begins to decrease again, so that 3 Mv rays may actually be "softer" instead of "harder" than 2 Mv. For lighter materials than lead the maximum of penetrating power occurs at rather higher energies (10–12 Mv for Al) but the existence of this maximum must be taken into account, and may offer difficulties in the development of absorption and filtering techniques which will have to be used with these multimillion volt machines.

But million-volt X-rays are really not new tools for biological work—they are only more powerful forms of tools already familiar. We must look to the results of experiments on the transmutation of elements for the really new possibilities which nuclear physics will furnish to biology. Among these the most promising are the last two listed above, namely, the neutron and induced radioactivity, and to these subjects I shall devote the remainder of this discussion.

THE NEUTRON

The neutron is a particle of mass 1 (actually 1.0090) and charge zero. It is one of the two fundamental building stones from which all nuclei are constructed, the other being the proton (mass 1.0076, charge +1). All nuclei are believed to be composed of these two particles and no others. Neutrons may be ejected from various nuclei by bombarding them with protons, deuterons, alpha-particles, or gamma-rays. And this, in fact, is the only way in which neutrons can be made available for use in experimental work. When radon (radium emanation) is collected in a small capsule containing powdered beryllium a convenient source of neutrons is obtained. The neutrons are ejected by the bombardment of the beryllium nucleus by the alpha-particles from radon according to the reaction

$$\mathrm{Be}^9+\mathrm{He}^4=\mathrm{C}^{12}+n^1.$$

The neutrons emerge with energies up to 13.7 million electron volts (Mev) though most of them have much lower energies.[3]

While the intensity of the neutron beam obtainable from a radon-beryllium source is sufficient for many purposes, enormously more intense beams have been produced by the cyclotron. Lawrence has reported neutron beams equivalent to what would be produced only by several hundred kilograms of radium and beryllium. The reaction often used in this case is the bombardment of beryllium by deuterons, according to the reaction

$$\mathrm{Be}^9+\mathrm{H}^2=\mathrm{B}^{10}+n^1.$$

[3] The kinetic energy which a particle of charge e (electrostatic units) acquires in falling through a potential difference of V volts is given by the relation K. E. $= Ve/300$. An uncharged particle such as the neutron which has the same kinetic energy which an electron (or proton or any other single charged particle) would acquire in falling through a potential difference of 1 Mv is said to have an energy of 1 Mev.

What, then, are some of the properties of neutrons so produced? In some ways a beam of neutrons is similar to a beam of gamma-rays. They are undeflected by a magnetic field and have considerable penetrating power through heavy substances. They were, as a matter of fact, mistaken for gamma-rays in the early experiments. A further examination shows, however, profound differences between neutrons and gamma-rays—and these differences may have biological importance. A gamma-ray loses energy in passing through matter largely through the energy it imparts to the orbital electrons of the atoms through which it passes. A gamma-ray, being an electromagnetic radiation, has strong interaction with charged particles (electrons) and these will sooner or later rob each gamma-ray of all its energy. A neutron, however, being an uncharged particle, is not at all influenced by passing through an atmosphere of electrons. Its course can be deflected or its velocity changed only by a close encounter with the nucleus of an atom, and this is a rather rare occurrence. Even when it does occur, if the nucleus against which the neutron collides is heavy, the neutron will rebound without much loss of energy, like a golf ball from a brick wall. The neutron is scattered but does not slow down.[4] The neutron is completely absorbed only in case it enters the nucleus, and is there captured or causes the ejection of another particle. In most substances this absorption probability is very small and the neutrons therefore penetrate great thickness—e. g., several feet of lead. On the other hand some substances, for example cadmium, have a very large selective absorption for neutrons of a particular velocity—and so rapidly remove neutrons of this particular velocity from the beam.

When neutrons pass through light materials, especially materials containing hydrogen, the situation is quite different. In collision with a hydrogen nucleus, which has about the same mass as a neutron, the neutron may lose a large fraction or all of its energy, imparting it to the proton, as in the collision of two billiard balls. On the average it gives up more than half its energy at each collision, and so in about 20 collisions a 5 Mev neutron will be slowed down to thermal energies (0.1 electron volt or less). Thus a beam of fast neutrons after passing through about 6 to 10 cm of paraffin will be largely slowed down to thermal energies. At these low velocities neutrons are readily captured by a proton to form a deuteron, and so are quickly absorbed. A block of paraffin or a water cell is thus an effective barrier for neutrons—though they could easily pass through several feet of lead. The technique of handling neutron beams thus presents surprising problems, which there is not time to discuss.[5]

[4] Inelastic scattering (slowing down) of fast neutrons by heavy nuclei has recently been discovered at Cornell.

[5] For a full account see Rasetti, Nuclear, Physics, Prentice-Hall, 1936.

The problem of detecting and measuring neutron beams is also an interesting one. Since neutrons do not interact appreciably with atomic electrons they produce almost no ionization along their paths. Hence, all the ordinary methods of detecting radiations (ionization chambers, counters, cloud chambers, etc.) which depend on ionization, are at first sight apparently useless. This difficulty is avoided by making use of collisions of neutrons with protons. The recoil protons produced in hydrogen-containing materials produce intense ionization, and the intensity of this can be taken as a measure of neutron intensity. The length of the recoil proton tracks produced in a hydrogen-filled cloud chamber can be used as a measure of the neutron velocities.

Still another method of detection is to make use of the disintegrations produced by neutrons in which alpha-particles are ejected, the alpha-particle ionization then being measured. The boron reaction is particularly useful:

$$B^{10}+n^1=Li^7+He^4.$$

This reaction is particularly efficient for low energy neutrons, for which the proton recoil ionization cannot be used. An ionization chamber lined with boron or filled with boron fluoride gas is widely used for the detection of neutrons.

Finally neutrons may be detected and measured by the amount of induced radioactivity they produce in certain materials such as silver.

It is evident from what has been said that the process by which a neutron loses energy in passing through matter is quite distinct from the processes by which gamma-rays or X-rays are absorbed. The latter give their energies to electrons while neutrons give their energy in appreciable quantities only to protons or other light nuclei. Electrons produce relatively small ionization over a long path; protons produce intense ionization over a short path; carbon nuclei, still more intense ionization over a still shorter path. Since it is to be expected that biological effects on individual cells will depend more on ionization density than total number of ions, it will be rather expected that neutrons will be more biologically effective than gamma-rays or X-rays of the same intensity. Preliminary experiments by Lawrence at California and by Zirkle of the Johnson Foundation indicate that this is indeed the case. Certainly this matter should be further investigated with great care and at once. As a matter of fact many experiments on neutron effects on both plant and animal tissue are now in progress, and there will be plenty of work in this field for many years to come.

There are difficulties in comparing neutron and X-ray effects which ought to be pointed out. X-ray doses are commonly measured in terms of the ionization produced in a standard chamber. Certain types of X-ray ionization chambers, however, may show almost no ionization for a neutron beam. A chamber used for neutrons must be lined with paraffin or Bakelite or other hydrogen-containing materials. The amount of ionization produced by a given beam will then depend greatly on the amount and arrangement of the materials introduced. Thus an X-ray and a neutron beam which produce equal ionization in one chamber will produce quite different effects in another one differently constructed. And the difference will depend on the energy (voltage) of the X-ray beam and the speed of the neutrons. On just what basis then can one say that neutrons are more effective than X-rays, or vice versa, unless there is some way of comparing intensities? Up to the present time each worker in this field has in general used a different type of ionization chamber, but in each case one has been chosen in which it was believed that the proton-recoil ionization would be comparable to what would be produced by the neutrons in biological materials. The results of different workers may be expected to be qualitatively comparable but it will soon be desirable to develop methods of quantitative measurement of neutron intensities relative to some arbitrary standard.

There is another important effect of neutrons which may be of biological interest. Both slow and fast neutrons are very effective in producing nuclear disintegrations, and in a large number of cases the disintegrations lead to products which are radioactive. (We shall have something to say about such materials later on.) In some cases also these disintegration reactions are accompanied by penetrating gamma-rays. A neutron is thus a "triple-threat man" since in passing through biological materials it may simultaneously (1) produce recoil protons or other nuclei, (2) create radioactive atoms, (3) excite gamma-rays. It may be necessary to treat individually the biological results of these three processes. In most cases it seems likely that the first will be most important since disintegration probabilities are less than collision probabilities in general. And the elements for which the disintegration probability (giving rise to gamma-rays or radioactive products) is high are not materials commonly present in biological tissues, e. g., cadmium, samarium, and boron. Nevertheless, one should be on the lookout for cases in which neutrons produce effects on materials containing very little hydrogen, which may be due to disintegrations rather than collisions. In the case of very slow neutrons (energies of a few electron volts or less) recoil ionization will be absent and their effects (if any) will be due solely to disintegrations.

It is possible that this property of neutrons of converting certain elements into their radioactive isotopes may be turned to good use. It might, for example, prove useful to direct a slow neutron beam at certain regions in the body and convert some of the elements present there into radioactive isotopes, whose radioactivity would remain for several hours after the neutron exposure had ceased. Since almost every element may be made radioactive by neutrons there are many possibilities to be considered. And this brings us directly, then, to a discussion of the possible uses in biological work of artificially produced radioactive materials.

INDUCED RADIOACTIVITY

It was in January 1934 that the Curie-Joliots reported that certain targets bombarded by alpha-particles continued to emit positrons for some time after the bombardment ceased. This positron activity was found to decay exponentially with time, just as in the case of the natural radioactive materials. By 1934 nuclear-physics technique was quite well developed so that further studies of this induced radioactivity were undertaken at once by many laboratories. And now, a little over 3 years after the first announcement, over 220 radioactive isotopes are known, including practically every element of the periodic table and some beyond the end of the table. (Radioactive isotopes of elements of atomic number 94, 95, and 96 were once indicated but are ruled out by recent work.)

The existence of these radioactive isotopes is easily understood. Each element in the periodic table has only a limited number (between 1 and 11) of stable isotopes which are found in nature. Thus fluorine has but one stable isotope, F^{19}; oxygen has three with weights, 16, 17, 18; and so on throughout the table, the heavier elements in general tending to have a larger number of stable isotopes. It is easy to see that many nuclear disintegration processes may give rise to isotopes of a particular element which are not found naturally and hence are presumably unstable. Thus one can produce F^{17}, F^{18}, and F^{20}, all of which are unstable. Such atoms can in general convert themselves into stable ones by the ejection of a nuclear particle, and they will do so in the course of time. In most cases this is accomplished by the ejection of a positive or negative electron.[6] These electrons are expelled usually with considerable energy and the ionization they produce is readily measured. Each unstable atom has a certain probable lifetime, which is shorter the more unstable its nuclear structure. So, just as in the case of a large population of individuals, the number "dying" per unit time is proportional to the total num-

[6] Electrons and positrons do not exist as such in the nucleus, but they may be created by the conversion of a proton into a neutron and a positron, or by the conversion of a neutron into a proton and an electron, the proper amount of energy being supplied or released.

ber "living." And if none were being born the total population would decrease exponentially with time. The period, or half-life, is the time required for the number living (and also the death rate) to decrease to half its original value. This is just the law which governs the radioactivity of the natural radioelements, such as radium.

As an example, if a C^{12} nucleus should capture a proton the resulting nucleus would be N^{13}, the charge and mass both being increased by 1. But N^{13} is not among the stable isotopes of nitrogen, though it could convert itself into the stable C^{13} by emitting a positron. This is what happens and it is found that N^{13} has a half-life of about 11 minutes. That is, if a large number of N^{13} atoms are formed at a given time the number of positrons emitted per second by the whole group falls to half its value in each succeeding 11 minute interval. It is in general possible by some nuclear process to produce from one to six or more radioactive isotopes of every element in the periodic table (except hydrogen), and in many cases a particular isotope may be produced by several different nuclear reactions. As an example the radioactive Na^{24} with a period of 14.8 hours may be produced by bombarding the stable Na^{23} by either neutrons or deuterons, by bombarding Al by neutrons, or by bombarding Mg by neutrons or deuterons; five reactions in all. The properties of Na^{24} are the same no matter how it is produced. On decay the Na^{24} atom emits a negative electron and becomes stable Mg^{24}.

A few of the radioactive isotopes of some of the elements which occur commonly in biological materials are listed in table I. The last column indicates how the isotopes are produced. For example the notation B-*d*-*n* opposite C^{11} indicates the bombardment of boron (B) by deuterons (*d*) with the ejection of a neutron (*n*), the reaction being

$$B^{10}+d^2 \rightarrow C^{11}+n^1.$$

TABLE I.—*Some typical radioactive isotopes.*[1]

Atomic number	Element and mass	Emitted particle	Stable product	Half-life	Produced by—
6	C^{11}	+	B^{11}	20.5 min	B-d-n, B-p-γ.
7	N^{13}	+	C^{13}	11 min	B-α-n, C-d-p, C-p-γ.
8	O^{15}	+	N^{15}	126 sec	N-d-n, N-p-γ.
11	Na^{24}	−	Mg^{24}	14.8 hr	Na-d-n, etc.
12	Mg^{27}	−	Al^{27}	10.2 min	Mg-d-n, Al-n-p, Mg-n-γ.
15	P^{32}	−	S^{32}	14.5 days	P-d-p, S-d-α, P-n-γ, etc
16	S^{35}	−	Cl^{35}	80 days	Cl-n-p.
17	Cl^{38}	−	A^{38}	37 min	Cl-d-p, Cl-n-γ, K-n-α.
19	K^{42}	−	Ca^{42}	12.2 hr	K-n-γ, K-d-p, etc.
20	Ca^{45}	−	Sc^{45}	2.4 hr	Ca-n-γ, Ca-d-p, T-n-α.
26	Fe?	?	Co	47 days	Fe-d-p.
53	I^{128}	−	Xe^{128}	25 min	I-n-γ.
80	Hg^{205}	−	Tl^{205}	40 hr	Hg-n-γ.
82	Pb^{209}	−	Bi^{209}	8.5 days	Pb-d-p.

[1] For a complete tabulation, see Livingston and Bethe, Rev. Mod. Phys., vol. 9, p. 359, 1937.

The other notations are similar, the symbols p, d, n, α, γ standing respectively for proton, deuteron, neutron, alpha-particle (He nucleus) and gamma-ray. In general the bombarding particle must have an energy of from 1 to 5 million electron volts. To produce reasonable amounts of radioactive material intense beams of such particles must be available. This requires a cyclotron or some form of high-voltage equipment.

The possibilities of using these materials in particular biological problems are so numerous that we can mention only a few by way of illustration. The more obvious possibilities (others are certain to come) may be grouped in two classes.

1. *Therapeutic uses.*—Radioactive isotopes of suitable elements may be injected into the body or directly into the organ to be treated. If it is found (and this requires much careful study) that the radiations they emit have definite therapeutic effects, then it is possible that induced radioactive isotopes may be more conveniently and effectively used than the naturally radioactive materials. Of particular interest is the possibility of selective irradiation of various organs of the body through the use of radioactive isotopes of elements which happen to be concentrated in those organs either under normal or diseased conditions. Thus one would use radioactive calcium or phosphorus for bone treatment, radio-iodine for the thyroid, etc., the active material going automatically to the spot where it is needed.

The clinical applications of these materials are thus both important and possibly spectacular. For this reason they have been perhaps prematurely hailed as a new boon to medicine. They certainly open up new possibilities, but their practical value is yet to be demonstrated and this will require a long period of careful research.

2. *Tracing.*—From the viewpoint of fundamental biology the use of radioactive materials as tracers is of far more interest than the therapeutic uses. In this field there are almost unbelievable possibilities which represent the most biologically promising of all aspects of nuclear physics. A prominent physiologist is quoted as stating his belief that the technique of using radioactive materials as tracers in biology may open a new era in that subject in as fundamental a way as did the invention of the microscope. The microscope made it possible to follow individual cells—the radioactive isotopes make it possible to follow individual atoms.

The uses to which this tool could be put are so many that it is as yet difficult even to classify them. Almost any chemical or biological problem in which it is desirable to follow the course of particular elements or compounds through a given system should be open to attack by this method. I will mention a few such problems which happen to have come to my attention for purpose of illustration.

1. The role of phosphorus in bodily metabolism.[7] Phosphorus is an extremely important element to both plants and animals; phosphates appear in the teeth and bones, and the internal organs contain phosphorus in the form of organic compounds, such as the phospholipids. Many important questions arise, some of which can be answered by chemical methods and some not. How much of the phosphorus intake at a given time actually reaches the bones and teeth? How long after intake does it arrive at a given point? How rapid is the replacement? By what path through the bodily organs does it arrive? How are all of these things affected by abnormal conditions of diet or of disease? All of these questions and more can be answered by administering radiophosphorus—in the food or otherwise—and then following the radioactivity as it appears and disappears in various organs, the blood, the bones or teeth. Radiophosphorus (P^{32}) can be made in fairly strong samples by deuteron bombardment of ordinary phosphorus. The radiophosphorus can be combined into any compound after it is activated, and can, therefore, be fed or injected in the most convenient form. The half-life of P^{32} is about 14.8 days, so the activity of a given strong sample may be followed for many months. It decays with the emission of an electron, going to S^{32} which itself is probably harmless but in any case would be formed in amounts far too small to produce observable effects. By periodically testing the activity of samples taken from various parts of the body—either during the life of the animal or after killing and ashing—the amount and rate of phosphorus arrival may be determined with considerable precision. The many possibilities are sufficiently obvious as to require no further discussion before this group. Some work along this line has already been undertaken at various laboratories, with preliminary results which show clearly the power, accuracy, and feasibility of the method. Some surprising results concerning phosphorus mobilization during certain diseases have already been indicated. I shall have to leave them to be discussed by those more familiar with biology than I am.

It is evident that similar studies could be made with almost any other element of interest; calcium, potassium, iodine, iron, etc. The only question which arises is whether there exists a radioactive isotope of the element in question whose period is sufficiently long to make the studies feasible. Here, of course, the physicist is somewhat helpless. He can make radioactive isotopes at will, but he has no control over the period of the resulting product; he must take what comes. Each isotope has its own characteristic period, determined by its own nuclear instability. The only hope is, if suitable periods of certain elements are not now known, that new isotopes will some day be discovered which are better adapted for such work. Nature has been

[7] The author is indebted to Dr. Wm. F. Bale of the University of Rochester School of Medicine for outlining the uses of radiophosphorus.

fairly kind in this respect in providing so many periods of suitable length, and you may be sure that physicists will be busy for some time to come finding new ones.

2. Evidently a similar technique instead of being used on the body as a whole may be applied to studies of metabolism within individual organs, in nerves or muscles, even in individual cells. Many physiologists have already recognized these possibilities, and some have already planned programs along this line.

3. As the chemical nature of viruses, of hormones, and of various gland secretions become better known it should be possible to follow the behavior of these important but elusive agents, or to gain further information about their chemical composition.

4. There are many purely chemical or biochemical problems to which the tracing technique would seem applicable. Studies of chemical changes accompanying respiration would seem to be possible with the use of radio-oxygen—though the known periods unfortunately are rather short. The possibility of tracing individual carbon atoms in various organic reactions might well open up a new field in organic and biochemistry.

I think these few examples will serve to illustrate the many possibilities—some of which will lie along lines which no one can now foresee.

From what has been said you will see that the power of the radioactive tracing technique results from the following fortunate facts:

1. Radioactive isotopes of an element are chemically identical with the stable isotopes and will therefore behave in precisely the same way in all chemical or biological processes.

2. The active isotopes can be detected in extremely small quantities. In some cases it is possible to detect the presence in a given sample of as few as 1,000 atoms of a given isotope. The presence of a million atoms would give accurately measurable results. This sensitivity results from the fact that impulse counters of various types, such as the Geiger-Müller tube counter, will register each individual β-ray ($+$ or $-$ electron) entering it. If the geometrical conditions are properly chosen, from 0.1 to ½ of all the β-rays arising in a given sample may be made to enter the counter. The fundamental law of radioactive decay is that the number of disintegrations occurring per second is proportional to the total number of atoms present, i. e.,

$$dN/dt = -\lambda N,$$

where $\lambda = 0.693/T$ where T is the half-life in seconds. Thus for $T = 1{,}000$ sec. $= 17$ min. and for $N = 1{,}000$

$$\begin{aligned} dN/dt &= 0.693 \text{ disintegrations per sec.} \\ &= 41.5 \text{ per minute.} \end{aligned}$$

This is an observable number, even if only 1/10th of the β-rays produced enter the counter. In the case of P^{32} it is easy to prepare samples giving more than 10^6 disintegrations per minute or about 20,000 per sec. Since $T=14.8$ days$=1.3\times10^6$ sec., we find $N\cong3\times10^{10}$ radioactive atoms. This is only about 10^{-6} microgram. And if 0.01 percent of this amount appeared in any sample taken from an organism it could still be detected.

3. While it is possible that the presence of radioactive material in large quantities in certain organs might have definite biological effects on them due to the radiations emitted, and thus give abnormal results in metabolism experiments, it seems evident that in most cases the doses given may be made sufficiently small as to preclude any important effects due to the radiation itself.

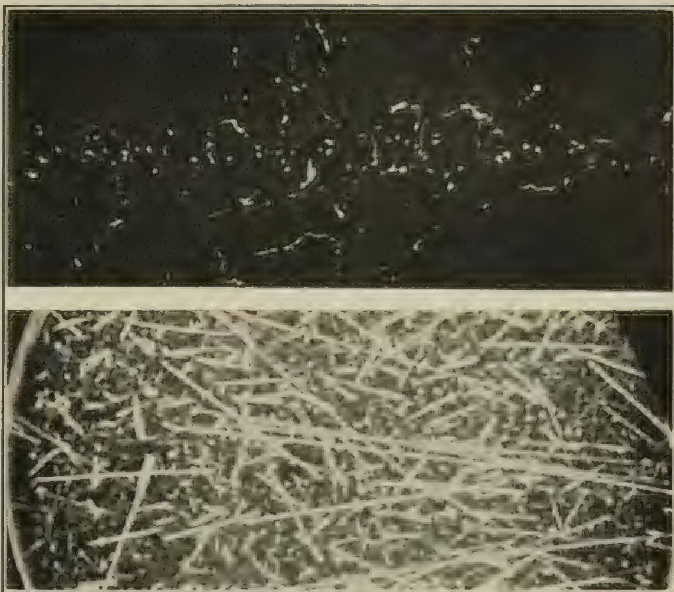
4. Finally—and this should be strongly emphasized—the technique of detecting and measuring the radioactivity of any material is simple and capable of good precision. And when one recalls the days or weeks of work required to make a quantitative chemical analysis of substances containing a few micrograms of the element of interest, and the utter hopelessness of detecting changes involving only 10^{-12} to 10^{-14} grams, one sees the radioactive technique as child's play. And when one recalls that this relatively simple technique not only detects these small quantities of material, but actually distinguishes between the atoms already present (which were not radioactive) and those introduced at a particular time (which are) the possibilities become quite exciting. It is almost as though each individual atom carried a red flag to herald its presence. (It is even better than this since we know too little of the biological effects of red flags!)

The most common instrument which will likely be used in such investigations is the Geiger-Müller tube counter. This device, undoubtedly familiar to you, consists of a conducting cylinder along the axis of which is suspended a fine wire. A potential difference of the order of 1,000 volts is applied between them. The whole is enclosed in a gas-tight envelope filled with air or other gas at a pressure of a few cm of Hg. A thin window must be provided for the entrance of slow β-particles. The counter wire is connected to a two- or three-stage amplifier which feeds a loud speaker or suitable registering equipment. The entry of a β-ray into the cylinder causes a click in the speaker, or the pulse may be used to operate a mechanical register. Counter tube, rectifier, amplifier, and registering device may all be contained in a box the size of a small radio set.[8] Observations consist merely in determining the number of registrations per unit time. Unfortunately such counters respond also to radioactive impurities which are always present in the air and in solid materials of

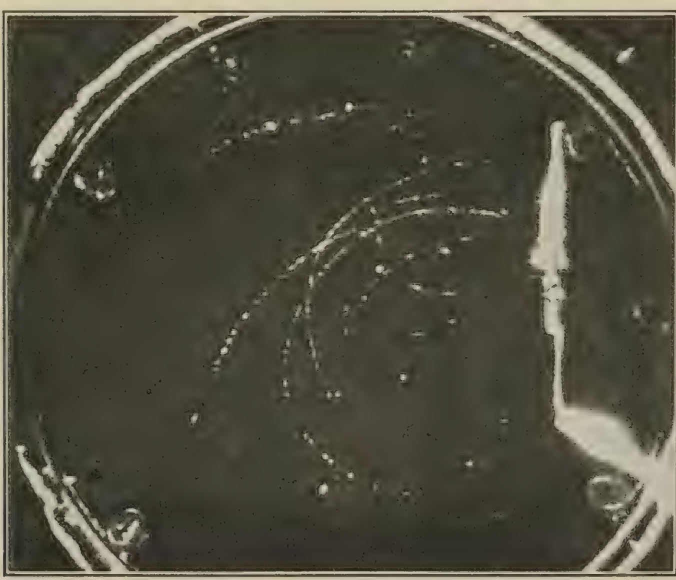
[8] For further discussion and references see Harnwell and Livingwood, Experimental Atomic Physics p. 412, McGraw-Hill, 1933.

the counter itself; and they also respond to cosmic rays. This means there will be a background of from 5 to 25 counts per minute which must be carefully determined and subtracted from the total observed with the source in place. It is this background which limits the ultimate sensitivity of the device, for the source being tested should produce a number of counts per minute at least as large as the background. Statistical fluctuations become important for low counting rates but can be reduced by extending the time of counting. A total of 10,000 counts must be made if the precision is to be as high as 1 percent, but only 100 counts will give 10 percent precision.

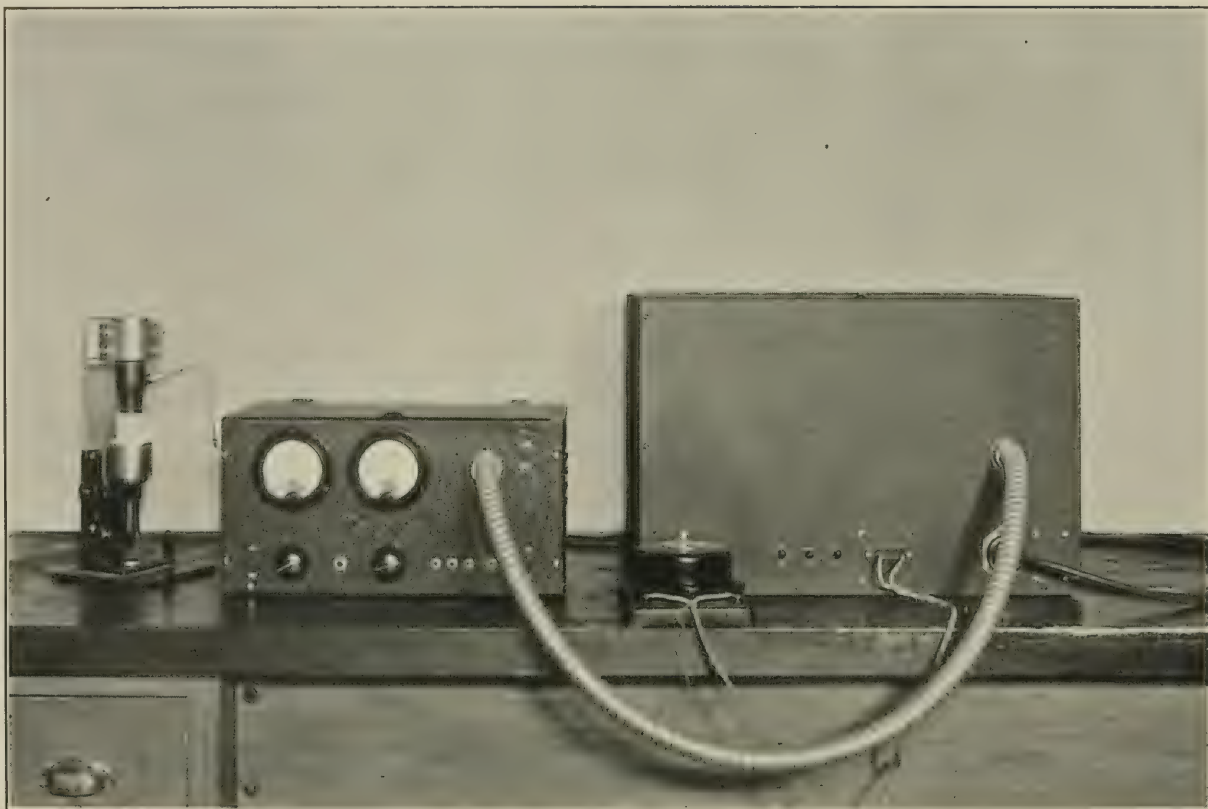
It is thus evident that simple readings of a clock and a registering device plus a little arithmetic is all that is involved in following atoms from place to place through even a complex biological system. It has been the experience that biologists who use this technique for the first time become wildly excited over the relatively simple way in which studies of most fundamental importance can be carried out. I shall expect this experience to be often repeated during coming years.



1. The difference in biological action between X-rays and neutrons is illustrated above. The upper figure made by C. T. R. Wilson shows the tracts of electrons ejected from atoms in a cloud chamber by X-rays, while the lower one made by E. O. Lawrence shows the recoil protons produced by neutrons traversing a cloud chamber.



2. Cloud chamber photograph showing the emission of positrons by radioactive nitrogen which was produced when the carbon plate shown at the right was bombarded by 900,000 electron-volt protons. (Anderson and Neddermeyer.)



THE NEW BIOLOGICAL "MICROSCOPE," A GEIGER-MÜLLER TUBE COUNTER, USED AT THE UNIVERSITY OF ROCHESTER FOR BIOLOGICAL WORK WITH RADIOACTIVE MATERIALS.

ELECTRON THEORY[1]

By R. G. Kloeffler
Fellow of the American Institute of Electrical Engineers

The discovery of the electron dates back to the beginning of the present century. This important event was foreshadowed by many early experiments and theories. In 1725, DuFay discovered that the gaseous region around a red-hot body would conduct electricity. In 1879, Crookes found that the rays in his experimental tubes were negatively charged particles. Edison's experiments with the incandescent lamp led to the discovery in 1883 that an electric current did flow from an incandescent filament to a plate in a vacuum but that it would flow in only one direction. This is known as the Edison effect. J. J. Thomson is generally given credit for the discovery of the electron because of his experiments and reports to the scientific world in a period shortly before and after the year 1900. He developed a very ingenious method for measuring the charge on the ion and secured an approximate value of the magnitude of that charge. Wilson and other scientists made some improvements on Thomson's method and secured other approximate values for the magnitude of the charge of the electron. It remained for an American physicist, Robert Millikan, to make further refinements in the method of measuring the magnitude of the charge and thereby secure results announced to the world in 1913 which were absolutely convincing as to the existence of and the value of that fundamental electrical charge on the electron. This electron was a minute indivisible negative charge of electricity having a very small mass. The term "electron" has always been associated with the negative charge while the term "positive electron" has been associated with another complimentary unit, the proton.

Four years ago a cosmic-ray photograph taken at the Norman Bridge Laboratory showed unmistakable evidence of the track of a particle having the same mass and the same magnitude as the charge on the electron but of the opposite sign. Thus was discovered the true positive electron, or what is often termed the positron. This recent discovery of the positron has raised many questions in the scientific mind and has tended to upset some of our well-accepted theories regarding matter.

[1] Reprinted by permission from Electrical Engineering, vol. 57, No. 1, January 1938.

NATURE OF ELECTRICITY

The scientific world has offered many theories regarding the nature of electricity. Benjamin Franklin's single-fluid theory was one of the first. His theory pictured a colorless, weightless, invisible fluid or "electrical fire" which could permeate all matter. A normal amount of this fluid caused a body to be neutral, an excess amount produced a positive charge, while a deficiency gave rise to a negative charge. Later theories were offered by Faraday, Maxwell, and others. It remained for the discovery of the electron to give a definite basis for theories and conceptions which would come nearer to satisfying the inquiring mind of man. Up until 1910 or later, it was generally conceded that no one knew anything of the nature of electricity, though

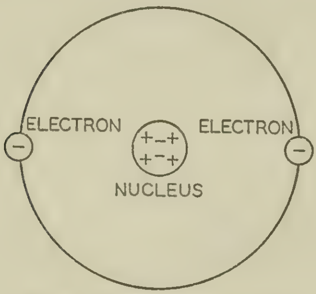


FIGURE 1.—Structure of the atom according to Bohr.

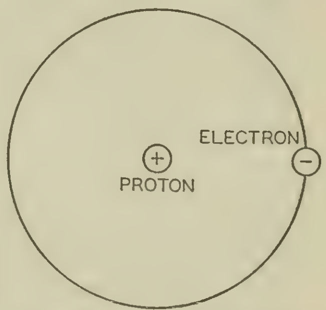


FIGURE 2.—Structure of the hydrogen atom.

men understood quite well many of the characteristics, properties, and laws of magnetism, electric charges, and electric currents. The general acceptance of the electron gave rise to new theories and conceptions in the fields of chemistry, physics, and electricity. The molecule had been long considered the smallest divisible part of matter, the atom the smallest division of an element, and now the electron, an indivisible and fundamental electric charge, a mere speck of electricity, became a part of the atom. Science gave the electron a mate, a proton, or a positively charged particle having the same charge as the electron but a mass 1,834 times as large. Then these two fundamental building blocks, the electron and the proton, became the basis of all chemical elements. The difference between the elements was determined by the number of pairs (electron and proton) going to constitute the atom. Bohr furnished a mechanical model or picture to show the structure of the building blocks within the atom. This model (fig. 1) envisions a structure like a small solar system having a nucleus surrounded by one or more particles moving in orbits. The nucleus has a positive charge and contains all of the protons in the atom. It may also contain a part of the electrons, with the remainder of the electrons moving in orbits about this nucleus. The hydrogen

atom has the simplest structure. It consists of a single proton constituting the nucleus with a single electron revolving in a surrounding orbit (fig. 2).

To get a conception of the relative physical size of this hydrogen atom, all parts of the atom may be imagined to be expanded until the nucleus, which is the proton, has the diameter of a baseball and is placed in Dallas, Tex. Then the lone planetary electron will revolve in an orbit which passes through New York City and San Francisco, and the size of this expanded electron will be 300 feet in diameter, or about big enough to rest comfortably in a football stadium or a baseball park. This picture shows the relatively "big hole" or empty space in an atom and explains why some electrons and atomic particles may be projected through many atoms before being stopped.

In order to explain radiation phenomena, Bohr assumed that there are a number of possible orbits in which the revolving electrons may move and that the jumping of the electron from one orbit to another is due to the absorption or radiation of energy. Consequently, the orbits are often referred to as energy levels. The orbits are pictured as circles or ellipses and usually as a combination of both in order to explain various atomic phenomena.

At the time when many electrical engineers were in the college classroom, teachers did not attempt to give any physical conception of the phenomenon of electricity or of the units of measurement which were employed. The scientist, the teacher, and the student of former days accepted electrical phenomena as a matter of fact, and, in common with the layman, said, "We do not know anything of the nature of electricity." Today there are some conceptions which have arisen from the discovery and measurements of the electron and from our pictures of atomic structure. Thus, to take the case of the phenomenon of attraction and repulsion of charged bodies, a positively charged body is one in which a large number of electrons have been removed from the body so that the total number of positively charged protons exceeds the number of electrons present. Thus the body has a strong attraction for electrons and it is said to be positively charged. In like manner, a negatively charged body has an excess of electrons above protons and this body exerts a strong attraction for protons, an excess of which may be found in a positively charged body.

ELECTRIC CURRENTS

Two bodies oppositely charged have a difference of potential between them. A difference of potential or voltage is measured by the work required to carry a unit positive charge from one body to another against the force of attraction or repulsion. The magnitude of the difference of potential depends upon the concentration of the charge

114728—39——17

and not on the amount of the charge. Thus an excess of a billion electrons on a sphere 10 centimeters in diameter would have only one-tenth as much potential as it would have if concentrated on a sphere 1 centimeter in diameter. The 110 volts at the ends of a lighting circuit are due to an enormous concentration of electrons along one wire and a corresponding deficiency in the other. When a human being contacts this circuit, the excess of electrons in one wire attempts to pass through the body to the other wire with a result well understood as far as one's feeling is concerned.

If a positively charged and a negatively charged body are brought in contact, electrons from the body with negative charge (excess of electrons) will move over to the body having the positive charge (deficiency of electrons) until an equilibrium of charge has taken place. This transfer of electrons from one body to another constitutes an electric current. Thus we can picture the phenomenon of electric current as a transfer or coordinated movement of electrons along a path or circuit. The protons do not move in solids because their mass is 1,834 times as great as the electrons, and because of their firm attachment to the atom itself. The magnitude of an electric current is determined by the number of electrons which pass a given point in a circuit per unit of time. To produce an electric current of one ampere, 6.3×10^{18} electrons must pass a point in one second. The individual electrons may move along the circuit slowly or quickly. Thus in a high-voltage vacuum tube, the electrons may move with a velocity approaching that of light, whereas in another part of the circuit they may drift along at a "snail's pace" of only a fraction of a centimeter per second.

The direction of the movement of electrons in an electric circuit is opposite to the conventional direction of current as adopted by scientists many years ago. Thus the early choice of direction of current was unfortunate in that it complicates conceptions and explanations in electronic devices. All remarks in this discussion will pertain to the direction of electron movement.

CURRENT FLOW IN SOLIDS AND LIQUIDS

An electric current in a solid is due to the movement of "free" electrons along that solid. The "free" electrons are not "extras" or those electrons above the normal number to balance the protons, but rather electrons which at certain instants are free from their parent atom to be moved on to another atom in a sort of relay race. Although the molecules are close together within a metallic solid, they do have a movement due to thermal kinetic energy and this movement increases with the temperature. The electrons, in turn, have a movement about their nuclei and at certain positions, due to the molecular action and the electron action, the electrons may become as close to

the nuclei of other atoms as their parent. At that instant the urge resulting from a difference of potential can easily move these free electrons along the circuit.

The passage of an electric current through a liquid is easily understood on the basis of the electron theory. Distilled water is practically an insulator but when an acid or base is added to the water it becomes a conductor. It appears that part of the molecules of the added material automatically dissociate into fragments or ions. Thus hydrochloric acid separates into H+ and Cl− and sodium chloride into Na+ and Cl−. This means that the H and Na atoms constituting the positive ion have lost one electron and are positively charged. In a similar manner, the Cl atom has an additional electron and carries a negative charge. If a difference of potential is applied to electrodes in the solution, the negative ions will travel to the positive electrode and give up an electron. In like manner, the positive ion will travel to the negative electrode and take on an electron. Thus the ions serve as carriers to convey electrons through the solution and this movement of electrons constitutes the electric current.

CURRENT FLOW IN GASES

Conduction of electricity through gases is produced through the medium of ions as in a liquid but the ions are produced in a different manner. Gas ions may result from the bombardment of gas atoms by high-speed electrons or ions, and by the action of electromagnetic waves of suitable frequency. If a high-speed electron is projected into a gas, it will collide with some of the molecules of that gas. The collision usually occurs with the electrons in the outer orbits of gas atoms. The result may be merely the change of direction of the flying electron or it may be the actul removal of an electron from the outer orbit of the gas atom. When the disruption of the atom takes place, the remaining part of the atom has lost an electron, is positively charged, and is called a positive ion. The electron which is removed may remain a free electron and as such it is a negative ion. It may join another neutral atom and thus form a negative ion of a different kind as far as mass is concerned.

The two gas ions formed by the bombardment of a single electron will move to electrodes having a difference of potential and placed within that gas. In transit to the electrodes these gas ions will collide with other gas molecules and if the difference of potential is sufficiently high and other conditions favorable, these collisions will result in the production of other gas ions. The latter ions may likewise produce still others while in transit to their respective electrodes. Thus ionization of a gas becomes somewhat accumulative in action and fairly large currents may result.

The collisions of electrons and ions with atoms are probably not physical contacts as when a baseball bat hits a ball, but rather the repulsion between the charges on the individual electrons and ions. The molecules of a gas are in a constant state of violent motion and the electrons, in turn, are moving about in their respective orbits. It can readily happen that the relative directions of motion of the electrons are such that an electron is caused to leave its parent atom and produce ions.

An interesting byproduct of ionization occurs when a colliding electron does not have sufficient velocity to produce ionization but does cause an electron in an outer orbit to jump to another orbit of higher energy level. The energy absorbed by this change of orbit is released in the form of a visible electromagnetic wave as soon as the electron drops back into its original orbit. The visible radiation or light is of a color characteristic of the element constituting the gas molecule. Frequently the light is monochromatic. This principle of light production underlies all of the gaseous and vapor electric illuminating sources, such as the neon, mercury-vapor, and sodium-vapor lamps.

RESISTANCE TO CURRENT FLOW

Electric resistance is that property of a circuit which opposes the passage of a current. It is easily explained on the basis of the electron theory. In a solid conductor resistance is due to the collision of the electrons which constitute the current with the atoms and molecules of that solid. The magnitude of the resistance depends on the number of free electrons available. In a similar manner, the resistance of an electrolyte or gas is determined by the number of ions produced and by the number of collisions between the moving ions and the molecules present. The influence of temperature on resistance is readily explained. In a pure metal a rise in temperature increases the kinetic thermal energy, speeds up the motion of the molecules, and hence tends to increase the number and the violence of the collisions, thus increasing the resistance.

It is of interest to note that the "hither and yon" movement of free electrons in solids does produce infinitesimal differences of potentials or voltages at the ends of conductors. These minute voltages introduce noise termed "resistance noise" in high-gain amplifiers and limit the smallness of signals which can be amplified satisfactorily.

ELECTRONIC DEVICES

The first electronic device was the two-electrode tube patented by Fleming in 1903 and known for several years as the Fleming valve. It took the place of the coherer as a detector of wireless telegraph signals. This device has grown to be the detector and the rectifier

of our modern electronic application. DeForest added a third electrode or grid to the Fleming valve and patented the three-electrode tube in 1907. For many years it was known as the DeForest audion. This device was primarily an amplifier of electric current, and it constitutes one of the greatest inventions of this century.

FREEING ELECTRONS FROM SOLIDS

The operation of most electronic devices depends upon the removal of electrons from solids in some manner. One method for removal is accomplished by impact on the solid of an electron, an ion, or the nucleus of an atom. A violent impact may splash electrons from the outer orbits of atoms lying in the surface of the metal. Electrons splashed out in this manner are known as delta rays.

Electrons may also be "brushed out" or released from a few sensitive substances by the impinging of electromagnetic radiations of suitable frequency. The electromagnetic radiations are light waves, either visible or invisible. This phenomenon of electron removal forms the basis of action in photoelectric cells.

A third method for the removal of electrons from solids is through the application of heat. This method is known by the term thermionic emission and is used in millions of electron tubes of today. The nature of this emission is not difficult to visualize. The electrons are bound to the atoms by their attraction for the nucleus. The electrons are bound to the molecules and to the substance of which they are a part by an attraction called electron affinity and the energy required to remove an electron from a substance is termed the work function. The molecules are in a constant state of agitation while the electrons, in turn, are moving about in the orbits of the atoms. The kinetic agitation of the molecules rises with the temperature and at a sufficiently high temperature the velocity of motion of a few electrons may become great enough to break through the surface of the solid. This escape of the electron is called emission and it may be pictured as in figure 3. Part *a* shows the emission at a relatively low temperature. At the higher temperature a cloud or atmosphere of electrons emanates or evaporates from the hot filament or cathode as shown in part *b*. When the electrons are hurled forth by their kinetic energy, they give to the cathode an image positive charge which exerts a force

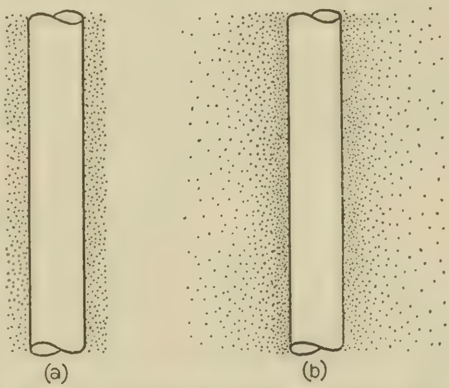


FIGURE 3.—Emission of electrons from a heated body.

of attraction. Thus as soon as the electron breaks through the surface, it is attracted back and, barring the presence of other fields and forces, it drops back into the cathode. Electron emission was studied by Richardson who reasoned that it was similar to the phenomenon of evaporation of liquids. Richardson suggested an equation now bearing his name for showing the magnitude of current emitted.

The materials used for cathodes which are satisfactory for electron emission are tungsten, thoriated tungsten, and oxide-coated alloys. Pure tungsten cathodes operate at a high temperature; they are strong and will withstand positive-ion bombardment better than the other emitters. The thoriated-tungsten cathode was developed by Langmuir and his coworkers. It consists of tungsten containing a small amount of thorium oxide. At a suitably high temperature the oxide is reduced to thorium which diffuses through the metal and forms a layer of pure thorium on the surface of the cathode. The thorium layer, one atom thick is the source of electron emission. Wehnelt found that certain oxides when placed on a metal base became excellent emitters at relatively low temperatures. Strontium and barium oxides have proved to be the best. During operation a thin layer of barium forms on the surface of the oxide and this serves as the source of emission of electrons.

ACTION OF ELECTRON TUBES

The value of nearly all electron tubes lies in their property of unilateral conductivity (that is, the ability to conduct current in one direction but not in the other). This property was shown in the "Edison effect" and was the basis of action of the Fleming valve. The reason for this property can be readily understood. Consider two electrodes placed in a tube having a high vacuum as shown in figure 4. Let F represent the cathode which is heated so as to be emitting a copious supply of electrons and P is the anode connected through a battery to the cathode. If the battery is connected so that P is positive with respect to the cathode, as in a, the negatively charged electrons will be attracted toward P and part of them will land on P, thus constituting an electric current through the vacuum. However, if the battery be connected so that P is negative with respect to F, as in part b, it will repel the electrons and no current will pass. Obviously, if an alternating source of potential be substituted for the battery, electrons will pass to P for those loops of voltage when P is positive but will not do so when P is negative. Thus this two-electrode device becomes a rectifier of alternating current. The factors which control the flow of electrons between the cathode and the anode or plate P are not entirely evident on the surface. Thus the number of electrons which pass to P in a tube having a high

vacuum depends first on the initial velocity of emission of the electrons which is determined by the temperature of the cathode; second, upon the attraction of the cathode for the electrons; third, upon the attraction of the plate which depends on the plate voltage; and, fourth, upon the space charge. The fourth factor, space charge, is due to the resultant charge in the space surrounding the cathode caused by the presence of the electrons which are being emitted. A cloud of electrons surrounding a cathode may be pictured as in figure 3. Each of these electrons is a negative charge and as such exerts a repulsion on all other electrons in its vicinity. At the instant a particular electron emerges from the cathode, all electrons in space are exerting a repelling force but as it moves away from the cathode all of those behind it are repelling or now aiding it toward the plate. The influence of space charge is very effective in a high vacuum and it was once believed that no emission would exist in a perfect vacuum. The two-electrode high-vacuum tube with tungsten filament is used for rectifying high voltages for use in radio-transmitting stations, X-ray equipment, smoke eliminators, and wherever a high continuous voltage is desired. The two-electrode vacuum tube is used as a detector in modern radio-receiving sets.

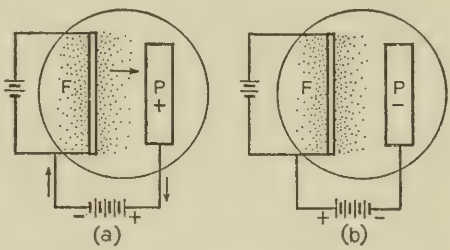


FIGURE 4.—Diagram of two-electrode tube or diode.

The addition of a small amount of gas to a two-electrode tube changes its characteristic action. The presence of the gas permits ionization to occur and the positive and negative ions thus formed pass to the cathode and anode, respectively. The ions serve as carriers of electrons and increase the current slightly but a large increase in current results from another action. Thus the negative ions formed are electrons and are attracted swiftly to the positive anode. The positive ions are atoms (less one or more electrons) and because of their large mass they move relatively slowly. Each positive ion can neutralize the charge on one electron in the space charge at a given instant, but because of its slow motion it serves to neutralize many electrons while in transit. Thus it is possible for a single positive ion to neutralize successively as many as 300 electrons in the space charge. The neutralization of the space charge permits the positive anode to attract many more emitted electrons and thus the current through the tube is greatly increased.

The gas-filled two-electrode tube is inherently a low-voltage device (that is, it has a low voltage drop from cathode to anode). It rectifies much larger currents than the vacuum type and is used for charging storage batteries and similar low-power D. C. applications.

CONTROL OF ELECTRON TUBES

DeForest added a third electrode, known as the grid, to the electron tube. In application in the tube, the grid (fig. 5) is a screen or wire mesh placed between the emitter or cathode and the anode or plate. The grid functions by means of a change of potential or charge upon its surface. This change of potential on the grid becomes an additional force acting upon the electrons surrounding the cathode and because of its nearness to the cathode exerts a very powerful influence upon the electron stream to the anode. The figure is a cross-sectional view which shows the usual location of the control grid in a three-electrode tube or triode. If a small positive potential be placed upon the grid, it will exert a relatively powerful pull upon all electrons which emerge from the surface of the cathode. This pull will be added to the effect of their initial velocity of emission and will oppose the repelling effect of space charge. The result of this action is that many electrons will move out farther from the cathode and come under the influence of the positive anode and thus pass to the anode. Any increase in the positive potential of the grid will cause still more of the electrons to move to the plate. Conversely, a small negative potential on the grid will repel every electron that emerges from the cathode and add its weight to the effects of space charge and cathode attraction. Thus many electrons which otherwise would be carried far enough by their initial velocity of emission to travel to the plate will now be held in check by the repelling force of the negative grid. It is obvious that a sufficiently negative potential on the grid would bar all electrons from ever reaching the anode. Thus it is apparent that a suitable variation of potential placed on the grid will control accurately the flow of current in the cathode-anode circuit. Since a mere change of potential does not involve any expenditure of power we have the strange phenomenon of controlling a large amount of power without the use of any power. In the actual application of the triode or three-electrode tube, the circuit for the grid does use some small amount of power. The triode thus is inherently an amplifier of alternating currents and as such it finds its greatest application.

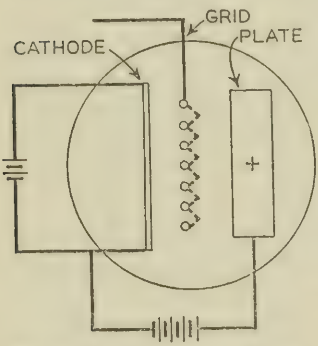


FIGURE 5.—Diagram of three-electrode tube or triode.

USE OF ELECTRON TUBES

Radio signals of telegraph, voice, or television are sent out through space by means of very high-frequency alternating currents called carriers. This method is necessary since lower frequencies will not

travel through space very far. The various low-frequency signals to be transmitted are impressed upon the high frequencies by a process of forming, molding, or modulating. At the receiving end of a radio circuit the impressed signals must be demodulated or detected and thus recovered from the high-frequency carrier.

The three-electrode tube or triode is used first as an oscillator in a resonant circuit for producing the high-frequency carrier current. Secondly, this type of tube is used to modulate or mold the low-frequency signal into the high-frequency carrier. In the third place, the triode may be used in the receiver as a detector or remover of the low-frequency signal from the transmitted carrier. Lastly, triodes are used in cascade for amplifying the feeble received signal so that it may be suitable for the desired purpose.

Additional electrodes, usually some type of grid, have been added to the three-electrode tube to increase the range of amplification, to improve the fidelity of amplification, or to prevent oscillations. The heavy loading of a triode by wide fluctuations in the grid potential and the resulting plate current may introduce distortion of the amplified signal and may produce oscillations because of the feedback of the grid-plate capacitance. To reduce such undesirable results, a fourth electrode known as a screen grid may be introduced between the control grid and the plate, as shown in figure 6. This screen grid is connected to a source giving it a fixed potential somewhat under the normal plate voltage. The screen then serves to establish a fixed potential in space giving a constant attraction upon all emitted electrons regardless of any variation of plate voltage and it greatly reduces the grid-plate capacitance.

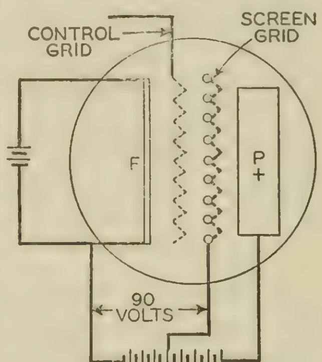


FIGURE 6.—Diagram of four-electrode tube or tetrode.

A curious phenomenon may result in the use of the screen-grid tube if a low plate voltage be encountered. Thus, at all positive values of plate voltage above 10 to 20 volts, the electrons hitting the plate produce secondary emission (splash out electrons from the plate). In the triode these electrons of secondary emission are attracted back to the plate but in the screen-grid tube for a certain range of low values of plate potential, the splashed-out electrons are attracted back to the screen grid (fig. 7). In special cases it is possible for more electrons of secondary emission to go to the screen grid than there are electrons arriving at the plate. Under this condition the plate current will reverse or become negative. Even though the plate current does not reverse, the electrons of secondary emission, which pass to the screen

grid, do introduce distortion in the tube when used as an amplifier under the conditions assumed. To prevent this phenomenon, which occurs only under abnormal conditions, a fifth electrode known as a suppressor grid is placed between the screen grid and the plate. This suppressor grid (fig. 8) is connected to the cathode or to ground potential. Thus a zero potential is established in the space between the screen grid and the plate. Under these conditions the screen grid has no effect on the electrons splashed out and all return to the plate so that no distortion can be introduced due to this cause. The electron tube containing the five electrodes is called a pentode. It will produce large power outputs with relatively small signal voltages applied to the grid.

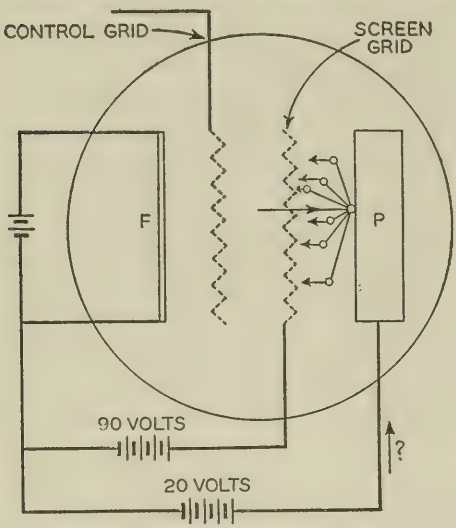


FIGURE 7.—Secondary emission in a tetrode.

RECTIFIERS

Recently the term mutator has been suggested to cover those forms of electronic devices which are designed for rectifying alternating current for power purposes. The term *mutator* thus includes grid-controlled hot-cathode *rectifiers*, mercury-arc rectifiers, and igniter-type mercury-arc rectifiers or ignitrons.

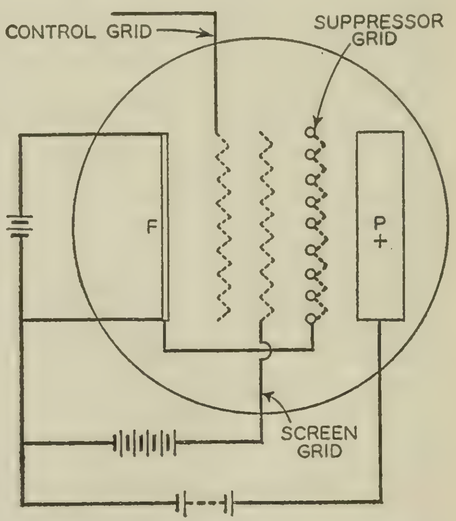


FIGURE 8.—Prevention of secondary emission by fifth electrode in a pentode.

If the vacuum-type triode previously discussed be changed by the addition of gas under low pressure and if the grid be changed so that it completely surrounds the cathode, then a tube possessing some different and desirable properties is obtained. If this tube be connected in the circuit of figure 9, practically no current will flow from the cathode to the anode when the grid is free or not connected to any source of

potential. This action is due to the fact that electrons emitted by the cathode land on the grid and make the grid negative. This negative grid repels nearly all electrons and does not permit many to pass through the meshes of the grid to the plate. If the grid is kept negative enough, the electrons cannot attain sufficient velocity to cause ionization and the tube is nonconducting between cathode and anode. As the grid is made less negative a point is reached where the electron velocity is great enough to cause ionization. Positive ions will then form a sheath around the grid and neutralize its effect and a large current flows to the anode. This current is limited only by the impedance of the anode circuit. Once started, the cathode-anode current cannot be stopped by any change of potential on the grid. If the grid circuit is opened, the positive ions will neutralize any electrons which land on the grid, and if the grid be made more negative, it will attract positive ions to its meshes and the resulting positive ion sheath will again neutralize the negative grid so that the cathode-anode current stream will be unaffected. The only way the anode current can be stopped when direct current is applied to the plate is to open the anode circuit.

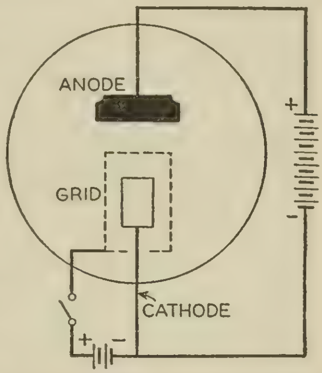


FIGURE 9.—Diagram of a grid-controlled gas-filled rectifier.

The hot-cathode grid-controlled gaseous-conductor tube or thyratron finds its usefulness when an alternating potential is applied to its anode circuit. Again, the tube can be started by placing a positive potential on the grid and the tube will function as a half-wave rectifier as long as the grid remains positive. If the positive potential be removed from the grid, the anode current will go to zero at the next negative wave of potential. Thus the starting and stopping of the rectification process can be controlled simply and perfectly (without arcing) by the application of a continuous potential to the grid. The grid may also be excited by a low alternating potential from the same source as the anode supply. If the grid and anode potential are in step, complete single-wave rectification will occur. If the grid potential be made to lag the anode potential, then rectification will start after the beginning of the cycle and the time and magnitude of the rectified current can be controlled. Thus a shift of phase of the grid voltage through 180° will vary the rectified current from zero to a maximum of half-wave rectification. The thyratron gives fine control of rectified current and finds a wide application in theater-stage lighting, flood-lighting, motor speed control, and elsewhere.

Mercury-arc rectifiers have been used for rectification for many years. They operate upon the principle of a hot spot upon a mercury-pool cathode maintained by positive-ion bombardment. The arc is started by means of an auxiliary electrode. During recent years mercury-arc rectifiers have been built in large capacities for supplying direct current for electric railway operation. These rectifiers have been built in large steel tanks and use 3, 6, or 12 phases with a corresponding number of electrodes for anodes. For starting the main arc an auxiliary or exciting electrode must be in operation all of the time. The ionization produced by this auxiliary electrode produces conditions favorable for an arc-back or a reversal of the rectified current. Hence the anodes must be very carefully shielded and the arc path must be relatively long.

Quite recently a new method for starting the mercury arc in the rectifier has been invented by Slepian and Ludwig. The device using this new principle is called the ignitron. The ignitron is a mercury-arc rectifier having a third electrode or ignitor which consists of a rod of suitable refractory material which projects through the side of the tube and has a point dipping into the mercury pool. The ignitor electrode serves to fire the arc at will just as the grid of the thyratron may start the gaseous conduction. If the ignitor electrode be made positive with respect to the cathode pool and a suitable critical current be permitted for a few microseconds, a tiny spark occurs between the ignitor and mercury. If the anode potential is positive and of suitable value, this tiny spark expands into an arc which is transferred to the anode through the ionization process previously considered. The arc forms a very low resistance path for the passage of current.

The ignitor principle may be used for a single current surge of half-wave rectification or it may be used for several waves, or for continuous operation. The ignition process must be repeated each time the alternating anode potential becomes positive. The ignitor electrode may be fired from the same A. C. source of potential as the anode. Also the phase relation of the ignitor voltage to anode voltage may be varied to give only partial or even zero time of rectification. Thus the ignitron has the same control characteristics as the thyratron. The ignitron is inherently suited for larger current values of rectified current than the thyratron. The advantages of the ignitron over the mercury-pool rectifier are long life of mercury-pool type of cathode, and low voltage drop in arc since cathode and anode may be very close together. The latter advantage results because no arc-back can occur on reverse cycle since firing occurs only at desired time (and not continuously due to auxiliary electrode). The applications of the ignitron include simple continuous rectification, rectification with control, motor speed control, welding, and circuit breaking with quicker response than mechanical devices.

PHOTOELECTRIC CELLS

It was suggested earlier that electrons may be ejected from some solids by the impingement of light rays. It appears that the high-frequency electromagnetic wave (visible or invisible) has the power of imparting energy to the electrons in the outer orbits of atoms of certain photosensitive materials so that these electrons are released or torn from the atom and fly out into space. This phenomenon forms the basis of action of the photoelectric cell or the "electric eye" which is so widely used in many control applications. The more common light-sensitive materials are sodium, potassium, barium, strontium, and some of their compounds. The photoelectric cell usually consists of an evacuated tube containing a large area of light-sensitive material and a small anode or wire near the center. The cell is connected into a circuit so that a positive potential is applied to the anode. Whenever light falls on the light-sensitive cathode, electrons are emitted and attracted to the anode. The actual current flowing in the cathode-anode circuit is very small and amounts to only a few microamperes at the best. This small current produces a small voltage drop across a resistance. This potential is amplified by means of other electron tubes to produce a signal for performing the purpose desired. The number of electrons emitted from a light-sensitive surface is directly proportional to the intensity of light falling upon that surface. Thus a variation of light intensity may be transformed into an electric signal to perform a desired purpose. This principle is used in the sound production for the talking picture where a sound track on the film varies the light intensity falling on a photoelectric cell. The photoelectric cell may also be used for picture transmission, for television, and for all kinds of signal applications.

Photoelectric cells may have a high vacuum or may contain gas under low pressure. The emission of electrons by the impingement of light rays is the same in both types. The resulting current to the anode in the vacuum type is equal to the electron emission, but in the gaseous type the current is amplified several times (in practice not exceeding 10 times) by the addition of current from the gas ions which are formed during the transit of electrons from the cathode to the anode.

GEOLOGY IN NATIONAL AND EVERYDAY LIFE [1]

By George R. Mansfield
U. S. Geological Survey

INTRODUCTION

To a surprisingly large number of people the word "geology" suggests nothing definite or practical, nothing associated with national or everyday life. Nevertheless, geology is concerned with the materials man uses in building his houses and great industrial plants. It deals with the metals of which his car is composed and with the fuels with which he drives his car or heats his house. It has to do with the seasoning and preservation of his food, with the water he drinks, and with the scenery which greets his eyes every morning. It considers the destructive hazards that form part of his environment in many parts of the world, such as floods, earthquakes, and volcanic activity, and is concerned as well with the gentler moods of nature that calm his spirit and inspire his imagination.

Minerals enter into all phases of our modern civilization. Geology deals with the occurrence and distribution of minerals and with the laws and forces that tend to create or destroy them. Industry must know where suitable supplies of minerals for its needs may be obtained and what conditions are imposed by nature on their successful recovery and exploitation. Federal, State, and local governments must know whether mineral supplies, within their respective jurisdictions, are of suitable quality or adequate to meet the needs of their citizens. They must have information on the geologic conditions affecting the sites of constructional works, such as dams, reservoirs, bridges, and the foundations of public buildings; on the problems of water supply and sanitation; and on the wise use and conservation of their mineral resources. The individual must earn his living and gain his inspiration amid surroundings from which geology constantly speaks to him. It seems pertinent, therefore, to consider in some detail the relation between geology and our national and everyday life.

[1] Address of the retiring vice president and chairman of the section on geology, American Association for the Advancement of Science, Indianapolis, December 31, 1937. Published by permission of the Director, U. S. Geological Survey. Reprinted by permission from Science, vol. 87, No. 2247, January 21, 1938.

RAMIFICATIONS OF GEOLOGY

Geology is concerned with all agencies and phenomena that have affected the earth in the past or are affecting it now. Some agencies, such as the sun's energy, act upon the earth entirely from without. Others act chiefly at the earth's surface. Among them are streams, glaciers, winds, and waves. Still others, such as volcanism, earthquakes, and mountain-building agencies, act chiefly within the body of the earth, though each of these may have strongly developed surface manifestations. Gravity acts from without the earth as an astronomical agency, but is also associated with every activity at the earth's surface and within its mass.

The geologist reads and interprets the geologic record in the rocks. But this involves consideration of the agencies above mentioned and through them the use of facts and techniques of other sciences, principally chemistry, physics, biology, and astronomy. A border zone lies between geology and each of these sciences so that whether an investigation is geological may depend on its viewpoint or emphasis rather than on the facts or techniques employed.

The borderline sciences, geochemistry and geophysics, have developed to consider problems that fall between the adjacent fields indicated by the names.[2]

Mineralogy may be cited as an example of the dependence of geology on other sciences. Mineralogy has long been dependent on chemistry and optical physics for accurate determinations of mineral species. More recently it has made use of the X-ray. Mineralogy applied to rock study has developed into petrology; similarly applied to the study of useful minerals it has developed into economic geology. Both geochemistry and geophysics are extensively utilized in economic geology, and geophysics has now become an important aid to the petroleum geologist in his search for oil and gas. However, the viewpoint of geology, the interpretation of the earth's history, is its own, and geology's dependence on other sciences is probably no greater than their dependence on it.

Geology ramifies also into business, national, and private life.

GEOLOGY AND THE MINERAL INDUSTRIES

The mineral industries include, generally, those dependent on the discovery and mining of mineral substances and their manufacture into useful products. They give employment to many thousands of our citizens. According to the Minerals Yearbook, 1937, published by the Bureau of Mines, the mining industry by itself ranks last among the four primary industries in the United States with respect to capital invested, value of products, or number of workers employed.

---

[2] For a broader interpretation of geophysics, see Hubbert, M. K., The place of geophysics in a department of geology, Amer. Inst. Min. and Met. Eng., Tech. Publ. 945, February meeting, 1938.

Actually, however, these industries are interdependent. Manufacturing needs minerals both for its machines and for the power to operate them. The products of mines contribute nearly two-thirds of the revenue freight handled by the railroads and about one-fourth of the ocean-borne traffic. Agriculture requires minerals for fertilizers and farm implements, and minerals serve to link farms and markets. Highways, railroads, trucks, and trains are all of mineral origin.

To those who actually mine coal, iron ore, and other minerals, the relation of geology to their everyday lives can hardly fail to be evident. The continuity of a vein, the nature of the ground, whether hard or soft, broken or stable, are factors which control the nature and speed of each day's work and the daily risk of personal safety. Similarly, the oil or water driller must keep close watch of the nature and attitude of the rocks through which he is drilling his well. Those who fabricate the product of the mines and wells are further removed from the direct effects of geology, but they are no less dependent on it, because their employment is contingent on the constant supply of a uniform material suitable for the manufacture of their special product.

Water is as truly mineral as petroleum or other hydrocarbons, and the question of adequate water supply is closely linked with mineral industries. Water is so essential to all phases of human life that no one can escape the consequences of failure, interruption, or contamination of his regular supply. An adequate supply of water is contingent on numerous factors, many of which are geological.

The economic geologist is employed to aid in the discovery of mineral resources, to work out their relations in the ground, and to obtain quantitative data on which to base estimates of reserves. He must consider grade and accessibility, as these factors ultimately determine whether a given mineral deposit can be exploited at current price ranges. The use of sound geological investigation and advice is essential if waste and suffering are to be avoided by the public when attempts are made to work an unprofitable mining property, to drill for oil in unfavorable places, or to unload questionable mining or drilling enterprises on the market.

Metals.—The geologist engaged in studying metallic minerals must devote a large share of his time in the field to the available underground workings in such mines as are accessible to him, besides acquainting himself with the surface geology of as much of the region as the limits of his time and funds will permit. He thus gains a better three-dimensional picture of the whole geologic set-up than would be possible from a study of surface relations alone. His maps, sections, and laboratory studies serve to control actual mining operations and guide explorations for further supplies of ore. The increasing use of geologists on the staffs of mining companies bears witness to

114728—39——18

the increasing need of the mining industry for geologic advice and to the growing recognition of that need.

Nonmetals.—In the field of nonmetallic mineral deposits the recognition of the need of geologic advice has grown more slowly and in fact can hardly yet be said to be widespread. Nonmetallic mineral resources are in general so abundant, lie so near the surface, and are so cheap, relatively speaking, that producers have given little thought to their geologic aspects. However, it not infrequently happens that a producer, say, of sand and gravel, locates his plant near a talus pile, which he mistakes for a bedded deposit of suitable thickness and quality. When further work discloses that the actual deposit from which the talus is derived is merely a thin cap at a higher elevation, he is faced with the problem of relocating his plant, changing its layout, or abandoning it altogether.

Some industries in the nonmetallic field utilize underground methods of mining. For example, mica, feldspar, talc, magnesite, gypsum, fluorite, and some phosphates are among the minerals so mined. More recently underground methods have been successfully applied to the mining of limestone, slate, sandstone, and even granite at different places. Special processes for recovering salt and sulphur by underground solution or melting and pumping have been devised which differ from ordinary mining methods, but the successful location and development of such an enterprise, as in the other instances, depends fundamentally on knowledge of the geology of the area in which lies the deposit to be mined, or otherwise recovered.

Again supplies of construction materials for building and other activities in the vicinity of large cities or large engineering projects tend to become depleted fairly rapidly and search for such materials has to be extended farther and farther from these centers. Here a good geologic map is of the greatest service whether or not it was originally prepared to serve economic needs. For regional planning, where constructional activities are contemplated, the areal geologic map of the United States has been found a valuable guide for more detailed investigations. Similarly, State geologic maps and geologic maps of individual areas, such as those provided in the folios of the Geological Survey, have repeatedly proved their worth in locating supplies of necessary construction materials. For example, the State geologic map of Alabama shows the distribution in the northern part of the State of extensive deposits of gravel in areas mapped as Tuscaloosa formation and large areas of valuable limestone for building in the Bangor limestone. Special economic maps, such as that of the Tennessee Valley, prepared by the Geological Survey, indicate the distribution of a wide variety of mineral deposits. The use of such information may often result in large savings both in time and money,

not only by pointing out more favorable areas but also by preventing search in unfavorable areas.

Fuels—coal.—Geologists in Federal and State surveys, as well as those in private employ, have labored many years to make known the nature and extent of the nation's coal resources. We now know in greater or less detail where the deposits of coal of different ranks, from lignite to anthracite, lie, how extensive they are, how rich in heating value, and which beds among them are best adapted for such purposes as coking and steam production. Some years ago the Geological Survey published a map showing the nature and distribution of the coal fields of the United States, which has proved a very useful summary. Although the number of publications emanating from these sources is large, the work is far from complete because of the wide distribution of the deposits and the refinements of study needed in getting desired information.

Petroleum and natural gas.—In recent years the search for new supplies of petroleum and natural gas has become increasingly the task of the geologist and the geophysicist. In this task paleontology has acquired greater economic interest and importance than in any other branch of the mineral industry. Fifty years or so ago, who would have thought that a matter of prime importance to a great industry would be the stratigraphic position and depth below the surface of certain beds of rock whose chief characteristic is their content of tiny fossils? Yet now in certain oil-bearing regions such beds serve to outline, or help outline, the shape, size, and position of oil and gas pools. Our knowledge of subsurface geology, on which the search for oil now largely depends, has been built up by the geologist, patiently gathering and comparing data from well cuttings and cores, identifying fossils—including many of microscopic size—determining mineral particles and preparing the maps and sections on which the collected data are assembled and summarized.

The geophysical prospecting now in wide use in the search for oil and gas derives much of its usefulness from the great body of data assembled and integrated by geologists. The effectiveness of geophysical combined with geologic methods has been well shown in many parts of the United States, especially in Texas and Louisiana near the Gulf of Mexico, where many oil fields and salt domes have been thus located, in California, where oil pools are being tapped at great depths, and more recently in the central Illinois basin. The geologist is indispensable to the oil industry. The literature on geophysical prospecting is increasing at a rapid rate. A quarterly Geological Survey bulletin of about 300 abstracts is now required merely to outline these publications.

The contributions of the petroleum geologists to geologic literature and philosophy have greatly stimulated interest in the deeper rocks and

structures of the earth's crust, in problems of sedimentation, ancient shorelines, and continental history. In this connection, David White's carbon ratio theory deserves particular mention. The essence of it is that organic substances in sedimentary rocks share in the ordinary metamorphic changes induced by compaction and folding of the deposits. Oils and coals of different ranks are produced and modified by these changes at relatively low temperatures and by a sort of cracking process, whereby the more volatile hydrocarbons are liberated while the fixed carbon remains, thus increasing the ratio of the "fixed" to the volatile carbon. As these metamorphic effects become more intense, the cracking process reaches a "dead line" beyond which no oil or gas pools may be expected. This theory explains many facts regarding the mode of occurrence of petroleum and some of the differences in its character from place to place. By indicating areas where the search for oil would be unprofitable, it has saved producers millions of dollars.

The relationship of geology to the life and interests of a community is nowhere more definitely recognized and more strongly appreciated than among the people living in the oil-producing parts of the country. Even a brief sojourn in such a community suffices to show that the common man has a keen understanding of such geologic terms as anticline, structure, dip, and strike, and of the part these features may play in finding oil.

GEOLOGY IN THE CONSTRUCTIONAL INDUSTRIES

In recent years the imagination of the public has been stirred by plans involving engineering construction projects on an unprecedented scale. Some of these projects are already in progress and popular attention has been directed to such centers as Norris, Tenn.; Guntersville, Ala.; Boulder Dam, Ariz.-Nev.; Bonneville Dam, Oreg.-Wash.; Grand Coulee Dam, Wash., and Fort Peck, Mont., where construction of large river-control projects is already well advanced.

The geologic conditions at each of these sites presented problems or even hazards that had to be solved and met by special engineering devices before success for the constructional end of the project could be assured. At one site, for example, the difficulties centered in the relative porosity and cavernous character of the limestones on which the dam was to be seated. At another, ground movement, through landslides, introduced serious hazards. At still another, the occurrence of large supplies of hot water denoting disturbed structural conditions at the proposed dam site had to be taken into account. The engineers in charge, mindful of previous disasters where work of this sort had been done without sufficient regard to attending geologic conditions, called upon geologists for help. As the sites selected

have special advantages not easily duplicated, it remained for the geologist and the engineer jointly to work out methods for overcoming these difficulties. This seems in large measure to have been accomplished, and the public has much reason to hope that the structures will prove stable when completed.

Some years ago the Government undertook the project of building a large reservoir in a western valley for the purpose of irrigation storage. The site had been selected after a careful investigation by a well-known consulting engineer, who reported that it had several advantages over competing sites and that the construction involved no special problems. When drilling began for the selection of a dam site, trouble arose from drilling water, which disappeared almost as fast as it could be poured into the drill holes. Geological investigation showed that the ground-water table in the vicinity of the proposed dam site was nearly 100 feet below the surface. The rocks on which the dam was to be seated were porous and fractured lavas, resting on thick but poorly consolidated and porous volcanic ash. The proposed dam would surely allow water to flow away beneath and around the dam without providing the desired storage. The site was abandoned, and the resulting saving to the Government in avoiding the unwise proposed construction was approximately $2,000,000.

Although the geologist is indispensable in helping to solve problems encountered in great constructional projects, he is even more necessary when it comes to the consideration of the sources of supply and the nature of the mineral substances that enter into any modern constructional project, great or small. At the time the Boulder Dam was under construction, the technical journals and locally the daily newspapers carried accounts of the enormous quantities of sand and gravel, cement, steel, etc., that were needed and used, and of special types of equipment designed to handle these materials. Similarly, for the other projects, much information of this sort is available.

Some years ago E. F. Burchard and G. F. Loughlin compiled construction data, not published, for the Interior Department, North Building, in Washington, D. C. This is a modern office building, completed for occupation in 1917. It occupies an entire city square. According to Burchard and Loughlin's figures, about 8,000 tons of metals, more than two-thirds of it structural steel, was utilized. Interesting items in this connection are 20 tons of bronze in locks and 49 miles of wire used in signalling and lighting but not for telephones. The nonmetallic minerals used total about 82,500 tons. Of this amount more than a third consisted of sand, gravel and crushed stone; clay products, largely hollow tile and building brick, made up another third. Then came Indiana limestone, plaster and cement and a number of others. These materials came from 28 States and 3 foreign countries.

Oliver Bowles, in the magazine, Stone, June 1932, gives an account of the stones used in the Department of Commerce Building in Washington. This building covers a ground area of approximately 8 acres and is one of the largest office buildings in the world. Indiana limestone was the stone most largely used. Of this about 700,000 cubic feet, or 1,100 carloads, was required. Granite from Stony Creek, Conn., amounted to 75,000 cubic feet. Other interesting items about this building include 7½ miles of corridor floored with terrazzo chips patterned with small tile; 6 miles of wall base along the corridors covered with polished black Isle La Motte, Vt., marble, and more than 16 miles of baseboard manufactured from slate obtained in the Pen Argyl district of Pennsylvania. The stones used in this building came from ten States and one foreign country.

The figures cited show something of the nature, diversity, and amount of the mineral substances that enter into the construction of large modern buildings. When one considers how many new buildings, both large and small, are being constructed throughout the country each year, and realizes that to obtain an idea of the total quantity of minerals used in their construction the figures given above must be multiplied enormously, he can better understand the meaning of the statistical summaries of mineral production published each year, formerly by the Geological Survey and now by the Bureau of Mines. These figures, of course, include not only the costs of minerals entering into building construction, usually f. o. b. mine or quarry, but the entire range of industrial and commercial activity in which minerals are used. For 1936, the latest year for which figures have been assembled, the Bureau of Mines shows a grand total of $4,582,000,000 for the value of the output of mineral products in the United States. The greatest contributor was mineral fuels ($2,706,300,000) followed by metallic products ($1,064,000,000). nonmetallic products ($789,700,000) and "unspecified" ($22,000,000).

It has been emphasized by geologists and economists, but will bear repetition, that the mineral resources of the country are diminishing assets. When once used they can only in relatively small measure be reclaimed and used again. Periodic mineral inventories, therefore, are essential to provide the best picture of our outlook regarding the future supplies and utilization of minerals, and these inventories are founded on geologic information.

GEOLOGY IN PUBLIC RELATIONS

Governments—Federal, State, or local—have many problems that involve some relationship with minerals, in the solution of which the geologist may and often does play some important part. The Federal Government and some of the States, for example, Texas, own large

tracts of public land, the administration or disposal of which involves a knowledge of the mineral resources that they contain. Many cities and towns own land from which stone may be quarried, or sand or gravel be removed.

Geological Survey.—The Federal Government, the largest landholder, early recognized the need of information regarding its public lands. Thus arose the succession of surveys, which finally led to the establishment in 1879 of the Geological Survey, whose director was charged with "the direction of the Geological Survey and the classification of the public lands and examination of the geological structure, mineral resources, and products of the national domain." Though many of its activities relate specifically to the public lands, the scope of the organization is broader, and it may do work for public purposes in any of the States, territories or insular possessions.

Its work has greatly expanded since the early days. The names of its six branches indicate the general scope of its present activities:

Geologic branch (includes wide variety of geologic studies and related chemical and physical work).

Topographic branch (topographic mapping, base maps, etc.).

Water resources branch (surface and ground water divisions).

Conservation branch (land classification, mineral leasing, power sites, etc.).

Alaska branch (geology, topography and mineral resources).

Administrative branch (includes library).

Besides geologists these branches employ many engineers, chemists, and physicists, a clerical staff and laborers. The continuous service of one or more legal advisers is also required. Nevertheless, the central purpose about which the entire organization revolves is the extension of geologic knowledge and the application of this knowledge to public problems involving the mineral wealth of the country, especially the public lands, and laws and regulations relating thereto.

Other Governmental agencies.—Other Government agencies besides the Geological Survey have need for geologists and geologic advice. Some of them call upon the Survey to do specific pieces of work or carry out special investigations. Thus the Survey has examined many tracts of land for the Forest Service in pursuance of legal obligations placed upon that organization to obtain such examinations prior to the purchase of additional lands for forest reserves. The Indian Service has requested mineral examinations of certain Indian lands prior to opening for settlement or disposal, and that organization and the Bureau of Reclamation have asked for dam site investigations. This last organization and some other bureaus originated in the Geological Survey. The Navy Department has asked for geologic aid in selection of sites for special structures and of tracts of land for petroleum reserves. The National Park Service has asked for geologic information for administrative purposes and to further the educational

and recreational use of the parks. The Tennessee Valley Authority has asked assistance in the valuation of mineral-bearing lands about to be flooded. The Reconstruction Finance Corporation and the Securities and Exchange Commission have called upon the Survey for advice in their respective fields as to applications for loans of public funds and as to issuing permits to sell securities based on underlying mineral properties.

On the other hand, a number of Federal organizations, recognizing the need of geologic information and advice, have attached geologists to their staffs or have built up separate geologic staffs in order to obtain more direct control of such work for their special purposes. Among these are the Army Engineer Corps, the Reclamation Service, National Park Service, the Soil Conservation Service, and the Tennessee Valley Authority. The increasing tendency of such organizations to seek geologic advice indicates a growing appreciation of the varied services geology may render.

State geological surveys.—Before the Federal Government took cognizance of geology as an aid to the better understanding and solution of its problems affecting mineral lands and resources, some of the States had established geological surveys and published reports. The two Carolinas, North Carolina in 1823, and South Carolina in 1824, were the first to take steps in this direction, followed by Massachusetts in 1830. From that time on more and more States have taken up geologic investigations. Most of the early surveys were discontinued, but many were revived, some of them several times. The New York Survey, however, has been broadly continuous in its activity and name since its inception in 1836. Now the only States that appear to make no specific provision for geologic work within their boundaries are Delaware and Massachusetts.[3] The State surveys, though held within State lines and thus restricted in their fields of operation, have given an excellent account of themselves and have rendered most valuable service to their people and to the country as a whole, as well as to geological science.

Services rendered by official surveys.—Besides the applications of geology in the fields of engineering, construction, and search for supplies of different minerals, which to a greater or less extent are regular duties of official surveys, its application in land classification, water-supply problems, sanitation, legal questions, and miscellaneous information service deserves attention.

Land classification was one of the duties imposed on the Geological Survey by its organic act, but little systematic geologic work was done in this connection until the rise of the conservation movement in the first decade of this century. Attention then was focused on such

[3] Massachusetts, through its Department of Public Works, in 1938 has undertaken a comprehensive, detailed study of its geology and mineral resources, in cooperation with the Federal Geological Survey.

mineral resources as coal, oil, natural gas, phosphate, and salines on public lands, and the interest of the Nation as a whole in their proper conservation and use was aroused. Congress passed legislation reserving mineral rights to the Government, setting up reserves for special purposes, and providing for the lease and exploitation of public mineral lands. A necessary corollary was the acquirement of more precise information regarding such lands. The Geological Survey thus began and has since continued systematic surveys to show accurately the distribution of these minerals with respect to the established subdivisions of the public land and to measure and sample the deposits for purposes of computing reserves. The acreage withdrawn from or restored to entry and the estimates of reserves have been modified from time to time as new information has become available. They have formed the basis of national planning and legislation. Besides this, land classification data are extensively used by the General Land Office in administering public lands.

Water supplies.—In the better-watered parts of the United States and other countries, questions of water supply have not, on the whole, seemed serious until recent years. The situation is different in more arid regions where water is the crux of the question, whether a given area can be used agriculturally or industrially, or perhaps at all. With the rapid expansion of cities in the more thickly settled areas and the increased demands for water in some western States, questions of water supply have assumed national importance. Investigations and measurements must be made both of the available surface water and of water in the ground. These are long-continuing projects because rainfall, which controls both the surface and the ground supply, fluctuates so that investigations, covering only short periods, are likely to be deceptive and undependable.

The problems of proper development and utilization of water involve the cooperation of the engineer, the geologist, and the chemist. The engineer is concerned with its production or accumulation, its transportation and handling as a commodity; the geologist with the character (thickness, porosity, etc.) and position of the water-bearing beds, their recharge from available rainfall and their possible contamination by salt water or other undesirable substances. With the engineer, he is concerned with the character and stability of rocks affected by tunnels, aqueducts, dams, and other structures. The chemist determines the quality of water as regards mineral and organic content. Mineral water, through clogging or staining, may be injurious for industrial use. Mineral substances in solution may also affect health. For example, fluorine detected in the waters of some of the southwestern States has proved injurious to the enamel of human teeth. Organic matter is deleterious to health.

Sanitation.—Closely related to the question of water supply is that of sanitation and the disposal of sewage and other wastes. If proper regard is not paid to geologic conditions, water supplies otherwise suitable may become contaminated. In some limestone regions where underground channels have been enlarged by solution, water may pass quickly from sources of contamination to places of use without being filtered or purified as they might be by passing through sequences of rocks of normal porosity. Thus the geologist's advice may be valuable to the sanitary engineer.

Legal questions.—Matters in litigation not infrequently hinge on geologic data. The mining industry has been afflicted by litigation in connection with the so-called "apex" law. Many distinguished geologists have participated in these affairs. Frequently the available data have been so incomplete as to allow many differences of opinion among the experts. Boundary disputes between States or individuals, where the position of a stream is involved, have frequently hinged on geologic evidence, as in the case of the Texas-Oklahoma boundary along the Red River some years ago.

Informational and miscellaneous services.—All the State geological surveys, as well as the Federal Geological Survey, are constantly called upon for a wide variety of information. Letters received at the Geological Survey from people in all walks of life run up into the thousands annually. Many mineral specimens are identified for the public. Work of this kind, including personal interviews, has to be considered a regular function of the geologist in public service. Sometimes the relation of geology to the question raised may at first seem remote, but the answer may reveal an intimate connection. For example, a representative of the United States Fish Commission called at my office one day. He was trying to restock with fish some of the streams in West Virginia. Though he was generally successful, there was one area where the young fish, when released, kept dying and he was not able to obtain satisfactory results. By referring to the county geologic map, a product of the State survey, it was found that the streams that caused the trouble all rose in or crossed a belt of pyrite-bearing shales, and it seemed probable that the unfavorable effects on the young fish were produced by sulphuric acid released by the decomposition and leaching of the pyrite in these shales, and its continual supply to the streams through springs or mine waters in minute quantities but sufficient to kill the fish.

Another West Virginia problem was brought to my office by an engineer from a telephone company that was having trouble in maintaining its lines. The company, it appeared, had laid these out with regard only to directions of route and mileage. It had not considered the nature of the ground in which its poles must be set. As a consequence disturbance of poles, disarrangement of line, and breakage of

wires were frequent occurrences because of land slips. Recourse to the State geologic map, another product of the State survey, with some further explanations, demonstrated to the engineer the usefulness of such a map in showing the position of the stable rocks that could be safely utilized and of the unstable formations that should be avoided.

GEOLOGY IN DOMESTIC RELATIONS

In the glaciated parts of the country, especially in New England, the land of many farms is stony. In the process of cultivation large numbers of stones, ranging in size from a few inches to as much as a foot in diameter, have been patiently gathered by the farmer and assembled in piles here and there in the fields or built into stone walls. Such walls are a characteristic sight along many New England roads. Successive winter frosts gradually lift other stones in the upper soil within reach of the plow and thus provide the farmer with additional crops of boulders.

Contrasting geologic conditions affecting the lives of whole communities have been called to public attention in the last year or two by the so-called "dust bowl" in the western States and by flooded areas of the Ohio, Mississippi, and other rivers. In the dust bowl area cultivation, deficient rainfall and high winds combined to loosen soil and transport it in large quantities to other sites near or far. The farms from which the soil was taken were depleted or ruined, whereas those that received it were improved, if not choked by too much sand or other deleterious material. On the other hand, the flooded areas suffered from the effects of too much rain and from the consequent increase in the transporting power of the rivers. One man's loss was perhaps another's gain in the redistribution of soil that took place during the flood.

An understanding of the effects of heavy rains and run-off on plowed ground is essential to a farmer if he is to conserve his fields and maintain the productivity of his farm. This is especially true if his fields slope more than a few degrees. The system of contour plowing now being introduced in many parts of the country, especially in the South, is doing much to prevent soil erosion and the waste of arable land.

My efforts to make a garden in Washington during the World War were directly affected by the geology of my back yard. The upper few inches of soil were derived from gravels of the Columbia group of Pleistocene age and were very stony, the stones ranging from bird's egg to football size. They lay on an old deeply weathered and rotted schist of pre-Cambrian age, the contact being beautifully exposed in a cut bank in the alley behind my house. Every square foot of that garden had to be opened by pick and shovel methods. Many wheel-

barrow loads of pebbles were taken out and fresh dirt that had been dumped on the hillside behind wheeled in. The rotted schist seemed to have the consistency of lead. Only by persistent effort was the soil lightened and made ready for cultivation.

The practice of insulating houses and office buildings has given rise to a relatively new industry. Some of the more widely used insulating materials are of mineral origin, and locating suitable supplies of them requires geologic investigation.

The question of keeping a cellar dry during a wet season, especially where frost and melting snow are involved, is dependent on recognition of the geologic conditions in the immediately underlying or surrounding ground. A ledge protruding into the cellar, or a water-bearing layer in the surrounding ground, if not properly sealed off, may lead water into the house and flood the cellar.

The location of cities, villages, individual dwellings, and farms without regard to existing geologic conditions, or perhaps in spite of them, has led to many disasters on both a small and large scale. This involves the whole question of disasters owing to earthquakes, floods, hurricanes, volcanoes, and other geologic agencies. Sometimes the advantages offered by such locations are great and the manifestations of adverse geologic conditions infrequent. Nevertheless, sooner or later they appear and those caught unprepared suffer. Special forms of insurance against disaster are available in some parts of the country. If the cost of protective measures is great, most people prefer to take their chances, but if under these conditions care is taken to select favorable ground and attention is given to protective types of building construction, the danger of disaster in individual cases, at least, may be largely obviated. However, anyone who elects to live in such places, should realize that potentially disaster-producing agencies are part of his natural environment and if he fails to take these into account he does so at his peril.

GEOLOGY IN EDUCATION

The field of education is broad, embracing all those facts, influences, and processes by which the student is made aware of the experience of the past and is prepared to go forward on his own initiative in the business of life and in extending the bounds of knowledge. Naturally many subjects enter into any well-rounded educational program. Some of them, notably geology, quicken observation, broaden understanding, stimulate the love of beauty, and cultivate the mind.

One of the greatest contributions of geology to education is the concept of the length of geologic time. This and the astronomical concept of distance in space are among the greatest contributions of science to human knowledge. They serve to put in perspective all happenings on the earth and throughout the universe. The later

methods of estimating geologic time, though permitting more exact statement of the lengths of individual periods or eras, emphasize the great age of the earth in contrast with the brevity of recorded history. Thus the age of the earth and the geologic record of the development of life upon it furnish a background for religion, philosophy, and social science.

Geography, a subject included in practically every educational program, rests on geology. The progress of life through the ages as shown by the geologic record has depended largely upon geologic conditions. Faunas have waxed and waned with the advance and retreat of seas over continents. Floras and vertebrates have responded similarly to the movements of the great ice sheets. The present distribution of plants and animals shows many peculiarities owing to these agencies and to isolation of certain inhabited areas from other corresponding areas by submergence or other geologic causes. The fauna and flora of Australia are well-known examples. The natural conditions that have favored the location of manufacturing or maritime cities, trade routes, and transportation lines are generally traceable to geologic causes.

History plays a great part in education. Many historical events from earliest times have had a geologic background. Tribes and nations have developed their own customs and habits according to whether they lived in mountain glens or broad alluviated country; on continents or islands. Great civilizations have arisen at the mouths or on the plains of great rivers. These favorable natural features are the products of geologic agencies operating on rocks of different kinds through long ages.

According to trustworthy authorities, the great deluge of Biblical days, as well as the devastating flood of this century at Galveston, Tex., was the result of a chance combination of hurricane and tide in low coastal and estuarine areas.[4] Mountain passes, products of geological agencies, have helped or hindered movements of peoples or armies. The Germans took advantage of the lowlands in Belgium in beginning their first advance in the World War. Accounts of battles have shown that the geologic nature of the terrain is always an important factor in any victory or defeat. However, the great underlying causes of wars are economic and depend in large measure upon the distribution of supplies of usable mineral raw materials whose origin and distribution are geologic problems.

The observation and study of nature is a prime element in any modern educational program. Nature is so full of geology that one can hardly look in any direction without seeing something of geologic interest. Classes in nature study may have different objectives, but

[4] The New England hurricane of September 1938 might be added here.

geologic materials and processes are always available and may either furnish the major interest or play some subordinate part. Geology lends itself readily to the inculcation of methods of scientific study. Either induction or deduction may be employed. The method of multiple working hypotheses outlined by Gilbert [5] many years ago is a noteworthy contribution to scientific education.

Geologic literature, like that of other sciences, or literature in general, contains much that is commonplace. Nevertheless, in the hands of its masters it has risen to heights worthy of the emulation of any student of English as well as of the sciences. Some years ago I came upon such a passage written by Sir Archibald Geikie.[6] It has lingered in my memory ever since. Discussing stratified rocks of pre-Cambrian age, he writes:

> Few parts of the stratified crust of the earth present greater interest than these earliest remaining sediments. As the geologist lingers among them, fascinated by their antiquity and by the stubbornness with which they have shrouded their secrets from his anxious scrutiny, he can sometimes scarcely believe that they belong to so remote a part of the earth's history as they can be assuredly proved to do.

The shores of the British Isles have suffered severely from marine erosion, fine examples of which may be seen at many places along their coasts. The islands are small enough to enable almost any one who so desires to view the activities of the ocean and the effects that winds, waves, currents, and tides have produced. It is therefore not strange that poetic and artistic genius should be stirred by scenes like these. Such may have been the background of Tennyson's poem, Crossing the Bar, which has brought peace and comfort to vast numbers of people.

Mendelssohn's celebrated overture to Fingal's Cave, still heard in symphony concerts, was composed after his visit to the Island of Staffa off the Scottish coast in 1829. Thus literature and art have been enriched by interested observation of geologic processes and products.

Sometimes art, as well as business, may be promoted by proximity of needed materials. Professor Shaler used to say that the reason Greek sculpture advanced to such heights of excellence was the fact that in the marbles of Attica the Greeks possessed an unrivaled medium for the expression of their art.

In the ordinary prosecution of his work the geologist brings to light facts, principles, and ideas of great educational value. His reports, papers, and discussions serve as the basis for textbook compilations, classroom studies, and field excursions. As a branch of scientific knowledge the cultural value of geology can hardly be overestimated.

---

[5] Gilbert, G. K., Amer. Journ. Sci., vol. 3, No. 31, pp. 284–299, 1886.

[6] Geikie, A., Text book of geology, 4th ed., vol. 2, p. 876, New York, 1903.

The literary value of its better products is high, its logic and broad philosophies stimulate the mind, and its factual content has world-wide interest.

SUMMARY

Geology, through its bearing on supplies of mineral raw materials, necessary adjuncts to our civilization, enters into many relations of local and national importance. The information it supplies is basic to many great industries. It enters also into more intimate human affairs. Truly it may be said that the relation of human life to geology is as close as that of a fish to water. The earth on which we walk, the air we breathe, the water we drink, the daily events of our lives and even our higher endeavors and aspirations, are ordered or affected by geologic phenomena and principles. Though mystery, in the sense of things we can not explain, enters into geology as it does into life itself, its commoner aspects are so clear, so instructive and so enticing if once sensed, that they can hardly fail to appeal to the imagination and interest of any active mind.

THE FLOOR OF THE OCEAN [1]

By P. G. H. Boswell, D. Sc., F. R. S.
Professor of Geology in the University of London, Imperial College of Science and Technology

Although Kipling's village of Huckley, led by 'Dal Benzaguen herself, may have voted that the Earth *is* Flat, it is undoubtedly a fact that general opinion, outside perhaps Zion City, Ill., holds to the view that it is a globe. But undue satisfaction in regard to our knowledge of this globe is hardly warranted when we remember that three-fifths of its surface is almost unknown to us. For this large proportion of the earth's crust (the lithosphere) is covered by the oceanic envelope called the hydrosphere. The margins of the seas have fluctuated since the earliest geological times and they fluctuate to-day; as the sonneteer observed:

> When I have seen the hungry ocean gain
> Advantage on the kingdom of the shore,
> And the firm soil win of the watery main
> Increasing store with loss, and loss with store, * * *

And notwithstanding its imperfections, the geological record has been fairly plainly written by these marginal fluctuations, but what lies beneath the depth of the ocean, being invisible and only slightly accessible, is still but little known. Yet when we are asked what contribution the progress of science is making to deep-sea lore, we can answer that during recent years significant advances have been made in our knowledge both of the form of the ocean floor and the deposits that cover it.

It is not the purpose of the present essay to consider the origin or the age of the great oceanic basins—whether they are primitive and original planetary features, or whether they have arisen by differential subsidence of parts of the earth crust or are "gapes" left by the drifting apart of the continents. These questions have been discussed almost ad nauseam during the past two decades: suffice it to say that the consensus of geological opinion does not favor the Wegener hypothesis of continental drift, although admitting the possibility that such drift may occur in certain parts of the crust on a

[1] Reprinted by permission from Science Progress, vol. 32, No. 125, July 1937.

114728—39——19

relatively small scale. This matter concerns us here only insofar as the form and covering of the ocean floors may throw light on the controversy.

The variation in depth of the oceans over the surface of the globe is familiar to all. In their main outline, the bathymetrical contours have long since been plotted, and the work of recent deep-sea exploration has only necessitated modification in detail of such contours. The broad distribution of deep-sea deposits—the organic oozes and red clay—in relation to depth is also a matter of general knowledge. The character of these deposits and the areas and depths of the floors where they occur was first made known from the classical investigations of the *Challenger* expedition in 1880, although earlier expeditions had foreshadowed some of the results. Since then numerous scientific explorations have been made, and have duly been referred to in textbooks of oceanography.

With certain exceptions, the types of deposits found on the ocean floor are related to the depth, the distribution of the various types corresponding with different submarine levels. A clear picture of the respective areas in relation to the heights or depths is furnished by what is known as the hypsographical curve of the earth's surface. From this diagram, in which areas are plotted as abscissae and heights as ordinates, it becomes evident that two levels are most widespread. The first is a land level consisting of the greater part of the continents (all but about 9 percent, which constitute the "mountainous" areas) together with a continental shelf that is submerged beneath the sea to an eventual depth of about 100 fathoms (nearly 200 meters) at its margin. The second is the deep-sea level, which includes most of the ocean floor; this, if regarded as lying between 1,400 and 2,800 fathoms (2½ and 5 kilometers) in depth, occupies about two-fifths of the earth's surface. The ill-defined stage connecting these levels, that is, the continental slope, is of small extent, possibly 8 percent of the earth's surface, and the deeps or sinks in the ocean floor lying below 3,000 fathoms in depth (5½ kilometers) constitute only about 4 percent of the surface, although this proportion may prove to be slightly greater when more records of depths are obtained. The deep-sea area, including the deeps, thus comprises some 115 million square miles (295 square kilometers), or more than half the earth's surface; the character of its surface and covering would therefore appear to merit greater attention than they have hitherto been given, especially when we recall the vast literature concerned with the geology of the continental areas of the globe.

Successive expeditions have added considerably to the number of sounding stations originally established by the *Challenger*, and we now realize that the ocean floor has topographical irregularities

no less impressive than those of the continents. Moreover, the employment during recent years of echo-sounding methods, so economical of time and labor, has revealed interesting features such as submarine canyons, deep hollows, and scarplike elevations. Now that some hundred canyons have been located, Prof. R. A. Daly has recently done good service by assembling the evidence relating to them. He notes that several occur along the continental shelf between the latitudes of Cape Cod and Cape Hatteras, including the classic "Hudson River Canyon" off New York City. Thirty examples have been found along Georges Bank off the New England coast and an even greater number between the northern end of Vancouver Island and southern California. Others have been determined off the Hawaiian Islands, in the northern and western parts of the Gulf of Mexico, off the western coast of Mexico, the Bahama Bank, the coasts of Brazil and Ecuador, the eastern coast of Korea, both eastern and western coasts of Japan, eastern and southern coasts of Formosa, off the mouths of the Ganges and Indus, and the coast of Ceylon. Around the African continent they have been proved to occur south of Zanzibar, off the south coast, opposite the mouths of the Congo, Ogowe, and Niger, and off the Gold Coast and Cape Verde. In Europe, they have been located in the region beyond the coasts of Portugal, France, and the British Isles. Thus their distribution is world-wide. Many extend as cuts through the continental shelf and reach a depth of at least 1,000 fathoms. Although some have no direct topographical connection with great rivers (for example, those closely spaced on Georges Bank), most are on the axial lines of such, notwithstanding the fact that delta-building is in progress. In relation to the continental shelf, they usually run straight down in the direction of slope—as though formed by rivers "consequent" on the shelf, their longitudinal gradients being from 1 in 100 to 1 in 10. Some are shallow, that is, not deeper than 50 fathoms (100 m) and confined to the area of the shelf, but many show depths reaching from 500 to 1,600 fathoms. Their walls are steep, the gradient being apparently from 1 in 3 to 1 in 1, and from the walls of those off California masses of fossiliferous Upper Cretaceous and late Tertiary clays have been dredged.

The mode of origin of these canyons has long been a problem—indeed, ever since the time when Buchanan attributed the classic example found off the mouth of the Congo to submarine river erosion. Some examples have probably arisen in this way, but it seems unlikely that submarine rivers can cut to great depths in relatively deep and quiet oceanic waters, even if we grant Daly's postulate, that such streams, being laden with mud, have increased erosive powers. Other canyons are probably tectonic; that is, are due to down-folding or

faulting of the earth's crust under the sea. But the problem in general remains.

Ridges, scarps, or deeps on the sea floor have been recorded from time to time, but latterly more precise information has been furnished by the work of the Dutch *Snellius* expedition and our own *John Murray* expedition in the Red Sea, Arabian Sea, and Indian Ocean. As the investigators on the *Snellius* expedition emphasized, the possibility of a submarine fault assuming gigantic proportions is not in accord with Wegener's theory of a plastic substratum which is necessary for the drift of continental masses. Thanks to Dr. Vening Meinesz's investigations of the value of gravity at sea, made by pendulum observations in submerged submarines, it has become possible to relate the deeps, which are usually long and narrow depressions of the sea floor, to long and narrow belts of strong negative anomalies of gravity. Thus there is more than a suggestion that such deeps are of tectonic origin, and consequently due to down-folding or fracturing of the crust. As has long been realized, the best-known deeps, such as those south of the Java-Timor arc and northeast of the Antillean arc, are situated in the neighborhood of land-masses where earth-building movements have recently been active. The same is probably true of the Nero Trough of the Marianas, the Atacama Deep and the South Sandwich Islands Deep.

We pass to the consideration of the deposits at present being laid down on this submarine surface of varied relief. We have as yet no evidence of any relationship between the canyons and deeps and the type of sediment deposited, but apart from these, it is generally true to say that the deep-sea sediments vary in character according to the depths of water in which they have accumulated. Several expeditions, notably the *Meteor*, the *Carnegie*, and the *Discovery II*, have recently provided additional information about such deposits, but it is a tribute to the work of the *Challenger* expedition that the classification introduced half a century ago still stands. The various expeditions of the research ship *Discovery II*, begun in 1925, are still in progress. Organized by the colonial office with the view of acquiring knowledge of the important economic problem of the feeding and breeding of whales in the South Seas, the personnel of the expeditions lost no opportunity of making scientific observations relating to the depth, salinity, and temperature of ocean waters, to marine life of all kinds, and to the character of sea-bottom deposits. Valuable results are gradually being published in a series of volumes, but inasmuch as many of the specimens must be examined by busy specialists, much information is still awaited, including the detailed descriptions of the floor deposits. But already results of surprising interest have been announced. The classification of the deep-sea deposits intro-

duced by Sir John Murray, of the *Challenger* expedition, requires modification only in detail: it may now be summarized thus:

Shallow-water deposits (between L. W. and 100 f.)	Gravels	Terrigenous deposits (containing detrital material)
	Sands	
	Muds	
Deep-sea deposits (below 100 f.)	Glauconitic mud	
	Diatomaceous mud	
	Diatomaceous ooze	Pelagic deposits
	Globigerina ooze	
	Radiolarian ooze	
	Red clay	

Except for the red clay, the pelagic deposits are almost entirely organic, and they fall into two groups consisting respectively of predominant calcium carbonate or amorphous silica. The calcareous materials include immense quantities of coccolithophores, which are calcareous algae, the well-known coccoliths being the separated plates of the skeletons; foraminifera, chiefly *Globigerina* and allied forms; and pteropods. The work of the German *Meteor* expedition demonstrated that in the Atlantic the coccolithophores are of wide distribution in the ocean, but the *Globigerinae* lived almost exclusively in temperate or warm water. The solubility of the skeletons of these organisms, which are composed of calcium carbonate, increases with pressure and fall of temperature, that is, with increased depth of water. The siliceous organisms consist of four groups: diatoms, silico-flagellates, radiolaria, and siliceous sponges. The diatom frustules are exceedingly small and enter into deep-sea deposits only where other remains, such as calcareous skeletons, are dissolved away, and where mineral material derived from erosion of the land is slight—as for example in Arctic and Antarctic regions. The occurrence of radiolaria in sea-water is similar to that of other plankton, but the main distribution of radiolarian ooze in the Pacific and Indian Oceans lies in the deeper regions, where the depth and low temperature have assisted in the solution of calcareous remains as they settle down. Recently Dr. E. Neaverson has noted the presence of radiolarian ooze among the samples collected by *Discovery II*, from the South Atlantic, a first record. Of these deposits, the globigerina ooze and the diatomaceous ooze together occupy a large proportion of the ocean floor, the former 50 million square miles, extending down to a depth of 2,500 fathoms, and the latter 11 million square miles, principally at a less depth and in the colder regions. But there remains a third deposit of even greater extent (52 million square miles)—the red clay, which is confined to the deepest regions, like the radiolarian ooze. It is found mainly in the Atlantic Ocean, though why it should occur there, and the other very deep-water deposit chiefly in the Pacific and Indian Oceans, is at

present not clear. The red clay is entirely mineral in character, consisting of particles of 2 microns (.002 mm) diameter, together with finer clay material. It has been regarded as in part the insoluble residue of the skeletons of organisms, left after solution of calcium carbonate, silica, and other constituents by subsidence through the great depths. But its mineral constitution does not lend support to this view, nor is it borne out by the characters of the insoluble residues shown by chemical analyses of skeletons of marine animals. More probably it results from the slow accumulation of fine volcanic dust, which is blown over the ocean for great distances, and from the decomposition of volcanic products such as ash, pumice, and basalt, which have fallen into ocean waters. In addition, however, to minerals such as felspar and augite (and in the clayey portion montmorillonite) which could be derived in this way, there are many tiny grains of quartz, a mineral unlikely to occur except rarely in products of oceanic volcanoes. The presence of these makes it seem likely that wind-blown material other than volcanic dust must reach the depths. Indeed, Stefansson observed that off-shore winds carried sand and even gravel far out on to off-shore ice, and others have recorded dust-falls derived from the Saharan region, at a distance of 1,700 miles west of the African coast. In the great 1912 eruption of Katmai in Alaska, a thickness of 6 mm of volcanic dust was deposited at 220 miles distance; also, the effects of dust from Krakatoa carried three times round the earth in 1883 are still remembered. Further, it has been observed that in samples from both the Narrow Seas and the South Atlantic relatively coarse grains of quartz are buoyed up by filamentous masses of flocculent protoplasmic or other organic material and can travel thus for long distances in the sea.

Little work has been done on the constitution of the clayey fractions of pelagic deposits, but preliminary X-ray investigations by Prof. C. W. Correns of Rostock showed that a sample of red clay collected by the *Meteor* is composed of kaolinite, calcite, and muscovite mica. There is here an extensive field for investigation.

When we recall how these pelagic deposits have arisen, we realize that the rate of accumulation must be extremely slow. Schott has estimated that in 1,000 years a thickness of 17.8 mm of blue mud, 12 mm of globigerina ooze, and less than 8.6 mm of red clay would be laid down. No surprise need be felt, therefore, at the oft-quoted statement that teeth of sharks dredged from the ocean floor, of species now extinct, have been found to be covered with only a film of deposit. On the other hand, there is the surprising record of some inch or two of globigerina ooze found covering the Atlantic cable when it was brought to the surface for repair. An inch of deposit in less than a century is almost incredible; and

we are obliged to consider the possibility of the cable having sunk in the ooze.

For many years before the *Challenger* expedition the pioneer methods of bottom-sampling by means of lead sinkers were followed, but subsequent improvements in technique led to the recovery of samples in valved tubes, that is, small borehole samples were obtained. Even then, only the surface layer of the sea bottom was penetrated. Efforts have therefore been directed to obtaining longer and still longer cores from the ocean floor; the *Meteor* obtained cores 1 meter in length, and the *Snellius* afterward brought up cores of a length of 2 meters or more. The possibility of obtaining a stratigraphical succession of floor deposits is fascinating to geologists, because clues to changing conditions of fauna, climate, and depth during geological ages may thus be yielded.

One of our own most versatile investigators, the late Prof. John Joly, of Dublin, devised a form of deep-sea apparatus for obtaining core-samples. More recently, Dr. C. S. Piggot, recognizing the necessity of improving on the results obtained by the ill-fated American research ship *Carnegie*, has devised a new type of apparatus, by which the contact of the sampler with the sea floor actuates the trigger of a firing mechanism and so forces the tube down farther than the few feet to which it would be driven by the momentum of the falling weight. Experimental work indicates that cores from 4 feet to 8 feet 8 inches in length can be obtained from depths varying from 200 to 1,250 fathoms.

Already, however, the older method of coring has shown the presence of different deep-sea deposits in superposition; of globigerina ooze resting on blue mud, and of red clay overlying globigerina ooze, as noted by Correns in his accounts of the *Meteor* samples. Now W. Schott's statistical studies of the fauna of South Atlantic waters indicate that at a depth of about 25 cm in the ooze, warm-water foraminifera such as *Globorotalia menardii* cease to occur, while *Globigerina bulloides* and *G. inflata* which favor cooler but still temperate waters increase in quantity. This kind of faunal variation, already conjectured by Philippi, the geologist to the *Gauss* expedition, suggests that the deep-sea deposits can furnish evidence of a climatic change. That the variation is not due to the drifting currents is shown by the similarity of the present distribution in the Middle and South Atlantic of *G. bulloides* in oceanic waters and in the superficial floor deposits. It is possible that the underlying deposits from which *Globorotalia menardii* is absent were laid down during a recent cold period—perhaps the last phase of the Ice Age. Further, if we assume that the area occupied by the limeless red clay is extensive because cold deep waters are strongly solvent on calcareous skeletons, the fact that red clay overlies a globigerina ooze, which in turn overlies beds with warm-water forms, suggests

that a warm period preceded the cold one. At the moment such conclusions may be speculative, but they point the way to promising investigations.

Many years ago it was deemed probable that the deep-water sediments were more highly radioactive than terrigenous deposits, although there was some doubt regarding the early determinations of radium contents by Joly and by Pettersson in the samples they examined, collected by the *Challenger*, *Albatross*, and *Princess Alice II*. More modern methods adopted by C. S. Piggot in the analysis of samples of globigerina ooze, red clay, and blue mud collected by the *Carnegie* have shown that the earlier conclusions were well founded. Only 28 sediments, obtained from stations scattered throughout the Atlantic Ocean, were tested by Piggot—a small enough number to represent such a vast area. With a few exceptions the specimens proved to have an extraordinarily high concentration of radium as compared with that of continental rocks, such as ancient sediments and granite, and even more so as compared with basalt. The general average of Piggot's analyses shows 6.52 g.$\times 10^{-12}$ radium per gram of sediment; for comparison, an average for granite might be assessed at 2.5×10^{-12} and for basalt at 0.8×10^{-12}, although many granites give a figure more like that of basalt. Exceptionally high contents noted by Piggot in sediments from the deepest parts of the oceans, such as red clay, reached 21.40×10^{-12} and 16.72×10^{-12}.

What is the source of this radium and what is the geophysical significance of the relatively high content of the coating of the ocean floor? To elucidate the first problem, Piggot turned to minerals believed to be in process of formation in the depths, and chose some of the manganese nodules which reveal growth banding with trapped clay layers between the coats of manganese oxide. Uranium was found to be fairly evenly distributed throughout a nodule, and the radium-content was high, although it varied in the different constituents of the nodules. The problem is therefore concerned rather with the parent uranium than with radium itself, and it has been suggested that the concentration is brought about by the numerous minute living organisms in the sea which extract, more or less selectively, the salts of uranium and radium from the sea-water, and incorporate them in their skeletons. When they die their remains take the radioactive material to the bottom with them. Piggot disagrees with this view, and also with that of Pettersson, who ascribed the high concentration to submarine vulcanism. The uranium in sea water must come ultimately from igneous rocks which are broken down on land. It is, of course, in solution in sea water, and if we are to judge by the radium content, it is in much the same proportions there as in ordinary rocks. Near the shore the radium content of the sediments only approximates to that of the ordinary rocks of the continent; thus the enrichment in

depth cannot be explained by detrital accumulation. Moreover, as stated above, red clays (which are the richest of the deposits) are believed to accumulate exceedingly slowly from decomposition of volcanic material, diluted perhaps by residues from skeletons of organisms and rare wind-borne detritus. Piggot suggests that although some uranium may be brought down by the settling of skeletal remains and volcanic dust, the greater proportion comes out as a result of oxidation at depth, for the oxygen concentration in sea water increases, according to the *Carnegie's* records, with depth below 1,000 fathoms. On the other hand, in shallow water or near to continents sufficient organic matter is present to maintain the reducing conditions, which tend to keep the uranium in solution. The environment at the bottom of the ocean being of an oxidizing rather than reducing nature, organic material disappears, and the water must be almost at saturation with respect to oxides of uranium. Thus there is a tendency for them to separate out like the oxides of iron and manganese.

The data obtained by the *Carnegie* regarding this increase in oxygen concentration throws light on various other phenomena and even on the color and composition of the deepest deposit—red clay itself, but they raise a difficulty when we try to explain the fresh and unoxidized condition of many of the minerals in deep-sea deposits. A considerable number of these minerals, as well as the fragments of volcanic glass associated with them, are of a type that is far from resistant to the effects of weathering, such as oxidation and hydration, on land. Reference is made below to the volcanic origin of most of such minerals. Well-known examples like olivine, augite, hypersthene, and biotite mica, are found in deep-sea sediments in a fresh unaltered state, often with crystal faces still sharply defined. Submarine "weathering," to use a contradictory term, cannot therefore proceed on the same lines as the corresponding process on the continents. If the conditions in deep waters are oxidizing, we may ask what it is that inhibits the process analogous to weathering (the "halmyrolysis" of some authors). We can only suggest possible explanations of this "stabilized" condition of affairs; for example, that (*a*) the waters are charged to saturation with carbon dioxide, (*b*) they are kept at an approximately low and relatively constant temperature, (*c*) the pressure is great, often exceeding 500 atmospheres, or even (*d*) light is absent.

From the foregoing, it will have become evident that there are three possible sources for the mineral material of deep-sea sediments deposited beyond the reach of river-borne detritus, namely, (*a*) the products of volcanic eruptions, either submarine or wind-borne from terrestrial outbursts, (*b*) nonvolcanic dust carried by wind from distant lands, and (*c*) detritus dropped from melting icebergs at extreme

distances from their source. A little further consideration may now be given to the effect of volcanic action.

Our attempts to penetrate the superficial layer of the ocean floor are necessarily very limited, and the likelihood of establishing the nature of the foundation rock of the crust is remote. But indirect evidence is afforded by the submarine volcanoes which are numerous and widespread in the oceanic areas. Many are of immense size and some rise, like Mauna Loa in the Hawaiian Islands, from the ocean depths to heights of 13,600 feet above sea level. Indeed, most of the islands which lie far from continental shores are composed exclusively of rocks which have cooled from the molten state, and mostly of rocks of volcanic origin as distinct from deep-seated origin, i. e., those that have solidified in the depths of the earth's crust. The rock basalt, familiar to all in the Giant's Causeway and the Hebrides, is of commonest occurrence in oceanic islands, and the broad similarity of the chemical composition of specimens from widely separated island localities points to derivation from a common subcrustal region or shell. In some islands there is a sorting-out of mineral (i. e., chemical) constituents, known as differentiation, which leads to the formation by crystallization of various rock-types, but these are rarities from the standpoint of total bulk.

It is common knowledge that when lavas are emitted from volcanoes on dry land, they not infrequently (like Vesuvius, for example) float up fragments of the "country-rock" more or less baked and sometimes in part assimilated at their margins. The "intrusive" representatives of the lava, that is, the feeders which become consolidated before they reach the surface, contain many more such "xenoliths." In a country where the crustal rocks are concealed by the volcanic pile, useful information is thus afforded of the nature of the superficial crust. But in oceanic areas such xenoliths of continental rocks are very scarce or not found in the lavas, the records that exist being nonproven. Hence has arisen the view that the foundation of the ocean is the same as that below the continental masses (or sial), namely, the subcrustal layer of approximately basaltic composition known as the sima. Support for this deduction is afforded by the rate of propagation of earthquake waves.

Volcanoes on land, or below the sea in maritime areas, are frequently of explosive type, the rocks being blown to fragments, even to dust, and the products distributed over a relatively wide area. The fragmental materials there consist of broken-up crystalline or glassy lava or disintegrated continental rocks. In the case of submarine volcanoes it is reasonable to suppose that if explosive action occurs (although it may be damped down by the great load of the ocean), the products would be distributed throughout the deep-sea sediments at present being laid down. Now, examination of large numbers of

these deposits from all over the ocean floor brings out the fact that (if we except certain occurrences not very far from land, or windborne, as mentioned previously) the detrital minerals are those confined to igneous rocks and frequently to lavas. Minerals which could have been derived only from ancient sedimentary and metamorphic rocks, like those which make up the continents, are strikingly rare.

In the reports of the *Challenger* expedition some 40 or more minerals were recorded from deep-sea deposits. All could have been derived from volcanic or intrusive rocks, or by growth in place: not one species is peculiar to continental rocks. The general impression given by the assemblage of minerals is intensified by the oft-recorded presence of volcanic glass, tuff, palagonite and pumice. It would be inappropriate to a general review such as this to cite long lists of minerals or to describe their characters. It is probably of more interest to pass on to a brief consideration of some of the newly-constituted minerals now being formed on the sea floor.

The problem of the mode of formation of such authigenic minerals in sediments has long fascinated geologists. The term authigenic denotes those minerals which have been formed in place, either contemporaneously with the sediment or at a later date, as distinct from the detrital minerals derived from the breaking-up of preexisting rocks. The *Challenger* expedition discovered several authigenic minerals in deep-sea deposits, among them being glauconite, calcium phosphate, phillipsite, and other zeolites, and manganese oxide (in manganese nodules). Among similar minerals, believed in some cases to be of authigenic origin in ancient sedimentary rocks, are soda-felspar (albite), potash-felspar (orthoclase and microcline), chlorite, epidote, pseudo-sillimanite, sphene, tourmaline, and others, many being somewhat complex silicates. We still hope that a more intensive study of deep-sea sediments may throw light on their mode of origin and perhaps even reveal them in actual process of formation. Recently, two interesting and unexpected authigenic minerals new to science have been discovered by Messrs. F. A. Bannister and M. Hey, in samples collected by the *Scotia* from the Weddell Sea. From a careful study of the chemical composition, optical properties and X-ray spectrograms of some minute crystals found in the samples, these investigators have described "envelope" crystals of a calcium oxalate dihydrate from a depth of 2,400–2,700 fathoms. Somewhat similar crystals have been found in cells of plants, in the gall of mammals and fish, and in renal calculi. The chemical composition of these deep-sea crystals suggests an origin in which organic processes played a part. They appear to have been formed in muds on the sea-bottom, here in an area of increased salinity, corresponding to a slight undersaturation of calcium carbonate. A second group of crystals, similarly investigated, proved to have the composition of hydrated calcium

citrate. The mineral has been named "Earlandite" in honor of the distinguished worker on foraminifera, who found them among the organic remains in samples he was examining. As calcium citrate has been found in plants, the presence of impurities such as Sr, Ba, Mg, Mn, Fe, and Cu in the crystals may be significant They came from a depth of 1,410 fathoms and are of very restricted distribution; their origin is conjectural. Bannister and Hey also found crystals of gypsum ($CaSO_4.2H_2O$) in samples collected by the *Discovery* in the Weddell Sea in 1925, from a depth of 2,800 fathoms. These gypsum crystals are of lenticular form up to 2 mm in length. Although they have not previously been found in oceanic deposits, they have been known for many years to be authigenic constituents of the muds of the Mersey Estuary. Their formation in the Weddell Sea, like that of the two new minerals mentioned, points to peculiar conditions, perhaps of deep-sea lagoonal character.

In review, we see in the history of the earth the operation of repetitions of the geological cycle of rock-erosion (earth-sculpture), transport and deposition of sediment, and earth movement leading to uplift. The interaction of the atmosphere, hydrosphere, and lithosphere, assisted by the thermal energy of the sun and the gravitational influence of the moon, results in the disintegrating work of frost, rain, wind, changes of temperature, and the waves. The geologists' music of the spheres, though not without harmony, resolves itself into two clear refrains—of degradation on the surface of the exposed earth crust, and synthesis on the sea floor. But the process of reconstruction is effected with impoverished materials, for the decomposition of rocks and minerals proceeds both mechanically and chemically, and the soluble products pass out of the geological cycle to a considerable extent by accumulating in ocean waters. All the known chemical elements are doubtless present in solution in the sea, but whilst calcium, silicon, iron, phosphorus, copper, and others are extracted to a greater or less extent by organisms, elements such as sodium, chlorine, and nitrogen accumulate. Against this increasing salinity of the sea, we must set off the formation of authigenic minerals on the sea floor, but we have no reason for thinking that this process bulks largely. A certain amount of compensation for the loss of soluble materials from the geological cycle is afforded by the delivery from subcrustal reservoirs of new rock material by volcanic action, but we have no means of assessing its effect in restoring the balance.

Prediction is dangerous, but we may go so far as to ask ourselves whether the pointers in geology are suggestive of an irreversible trend to an uninteresting uniformity. On the earth's crust, the breaking-down of minerals and rocks, many of which are complex silicates, results in the liberation of the elements which form more

soluble compounds, the alkalies, calcium, magnesium, and so forth. The insoluble residues are ultimately of clayey character, such as hydrated silicates of aluminium and oxides of aluminium and iron. Hitherto, we have distinguished between mechanical disintegration and chemical decomposition as processes of degradation, but recent investigations by Prof. A. Brammall of the Imperial College of Science and Technology, as beautiful in their simplicity as they are significant in their wide repercussions, have abolished that distinction. For Professor Brammall has extended the work of Tamm and Stevens by demonstrating that fine grinding of most common rock-forming minerals brings them into a condition when they are hydroscopic and become partially dissociated in water, so that the elements of the alkalies and alkaline earths are liberated.

Ultimately, then, the finer suspended material which reaches the deeper parts of the sea consists almost exclusively of simple hydrated silicates of aluminium in a fine state of division, that is, clay. In addition to this detrital accumulation there are the deposits of calcareous and siliceous materials formed by organisms. It would seem that there is thus an almost complete differentiation into a solution (sea water) rich in its diverse dissolved elements, and "dull" floor deposits of very restricted composition. Such must be the tendency unless synthetic processes are proceeding in the depths to form new minerals. J. L. Thiébaut claimed to have proved in 1925 that marine clays were usually composed of complex silicates of aluminium, iron, potash, calcium, and magnesium, in contradistinction to fresh-water clays which are largely silicates of aluminium with a little iron and magnesium. We may ask then—or formulate the question as a problem for investigation—whether the elements in sea water are being restored to the accumulating simple clays in the depths of the sea, a region termed by Correns "Nature's laboratory," although perhaps to speak of "factory" would be more appropriate. But in the meantime even our small knowledge of the processes at work convinces us, with Shakespeare, that "clay and clay differ in dignity."

ICE AGES [1]

By Sir George Simpson, K. C. B., F. R. S.

[With one plate]

It is now common knowledge that there have been great changes in climate during past ages. The geological evidence is perfectly clear that luxuriant vegetation once grew in Greenland and Spitsbergen, where now the hardiest forms of vegetable life can barely exist on the small areas free from permanent ice. At the other extreme, there is no doubt whatever that at one period a great ice sheet covered the plains of Central India and discharged icebergs into a sea covering what is now the Punjab and North-West India—one of the hottest parts of the earth.

From the geological record it would appear that the climatic changes of the past were in all directions, some warmer and some colder, some wetter and some drier than at present; and some individual localities appear to have experienced all possible climates at one time or another.

It is the problem of meteorologists to study the extent and sequence of the climatic variations in all parts of the world and to seek the cause and mechanism of the changes. Very little progress has been made in that direction up to the present for two main reasons. In the first place, the geological evidence is very fragmentary and often doubtful; and secondly, we know very little of what causes climatic variations and how they are controlled.

The geological evidence of change of climate is based on the fossil relics of past vegetable and animal life and on the physical effects which climatic conditions have on the surface rocks. The former is very difficult to interpret. Heavy vegetation does not always mean warm damp conditions, and both plants and animals may, in the course of ages, change their habits so that the early representative of a species which is now warmth-loving may have been developed in cold surroundings. For this reason, one cannot be certain of climatic conditions deduced from the remains of vegetable and animal life.

The case is quite different when we base our climatic deductions on the physical features of old land surfaces. There can be no doubt when we find traces of salts left when an enclosed sea has dried up that we are dealing with a dry climate in which the rainfall was less

[1] Friday Evening Discourse delivered at the Royal Institution on December 10, 1937. Reprinted by permission of the Royal Institution from Nature, vol. 141, No. 3570, April 2, 1938.

than the evaporation. But of all evidences of climate those of ice are the most unmistakable. At the same time one has to be careful, for today the presence of ice does not always mean a cold climate. In mountain regions glaciers descend the valleys into climates which are far from arctic, and in New Zealand especially, ice action is taking place in valleys which bear an almost subtropical vegetation. There have been periods in the past when ice formation was much more active than at present and of such an extent that only a radical change in climate can have been responsible.

The evidence of the presence of ice during these periods in places where ice is quite impossible with the present climate is so clear that these Ice Ages, as they are called, are the most appropriate subjects for the study of climatic change. If we can find a cause for an Ice

FIGURE 1.—Pleistocene glaciation: Ice on land shown by white, ice on sea shown by light stipple.

Age we shall have made a long step forward toward explaining all changes of climate.

PRE-CAMBRIAN ICE AGE

In the early days of geology, when evidence of tropical vegetation was found in regions which are now far from the Tropics, it was supposed that the high temperature required by these plants was due to the earth still remaining hot from its earlier molten state. The discovery, however, of clear evidence of ice in pre-Cambrian times, that is, at a time far anterior to the appearance of vegetation, shows that the earth had by then already cooled to its present temperatures. Evidence of pre-Cambrian ice has been found in North America, Europe, China, South Africa, India, and Australia. Some geologists have concluded from this widespread evidence of ice that the pre-Cambrian Ice Age was extremely severe. So little is known, however,

about this early age, and there is no evidence that all these places were glaciated at the same time, that it is useless to try to reconstruct the climatic conditions which then existed. The only certain conclusion is that already stated, namely, that the temperature of the earth was then already sufficiently low to allow of ice formation.

PERMO-CARBONIFEROUS ICE AGE

After the pre-Cambrian Ice Age, there is little or no evidence of extensive ice until toward the end of the Carboniferous Period or the beginning of the Permian Period, when evidence of extensive ice appears. This period is called the Permo-Carboniferous Ice Age. The chief regions where the ice was extensive and the evidence undoubted are in South America, South Africa, Australia, and India. The latter is well within the Tropics, and the evidence is perfectly clear that an extensive ice sheet existed at sea level in the Central Provinces, India. It is of great importance to notice that, so far as the evidence goes, the ice at this time was all situated within 40° of latitude of the Equator, and mainly in the Southern Hemisphere. Most geologists consider that at the same time the north polar regions had much higher temperatures than at present, luxuriant vegetation growing at this time in both Greenland and Spitsbergen.

This would mean that while there was glaciation within the Tropics leading to vast ice sheets at sea level, there was an almost subtropical climate in polar regions. This is a reversal of the climatic belts which no meteorologist can accept. Owing to the shape of the earth, the equatorial belt must always be warmer than the polar regions. The only explanation the meteorologist can give—and it was given by Wegener—is that the continents were not then in the same position relative to the Pole as they now occupy. In other words, the continents have moved since Permo-Carboniferous times.

THE PLEISTOCENE ICE AGE

After the Permian Period, there was another long stretch of time without any marked evidence of ice. This interval includes the whole of the Secondary and Tertiary divisions of geological time.

Evidence of ice was not entirely absent during this period, but geologists are of the opinion that the climate of the world as a whole was warmer than at present. In any event there was nothing equivalent to the extensive ice fields which left their traces in the pre-Cambrian and the Permo-Carboniferous Periods.

The Tertiary ended with the Pliocene Period, when without doubt the climate of Europe was definitely warmer than at present. Toward the end of the Pliocene Period the temperature commenced to fall in Europe, and evidence of ice made its appearance. Some time between

114728—39——20

the end of the Pliocene Period and the present time, that is, geologically speaking, during the Pleistocene Period, there was a great extension of ice in all parts of the world.

The map (fig. 1) shows the area which was under ice at some time or other during the Pleistocene Period. The north polar ice cap extended outward, reaching latitude 38° N. in North America, 50° N. in Europe, and 60° N. in Asia. In the British Isles the ice sheet extended as far south as the Thames Valley but did not cross it. The ice covering of the Antarctic was then much thicker than at present, and Meinardus estimates that the flow of ice from the Antarctic continent into the surrounding seas was at least three times as much as at present.

Not only were the polar ice caps more extensive and thicker, but also the mountain glaciation was much developed and the glaciers reached much farther down the valleys. The evidence shows that this was so in all parts of the world. Not only were the mountains which now carry ice more heavily glaciated, but also many mountains which now carry no permanent ice had extensive glaciers upon them.

Detailed study of the deposits left behind by the ice shows that there was more than one advance and retreat of the ice during the Pleistocene Period. Glacial and interglacial epochs have been detected in all regions which were glaciated, both in regions covered by the extended polar ice caps and on the glaciated mountains. The history of the Pleistocene glaciation has been most completely studied by Penck and Brückner in the Alps. The result of their work is summarized in figure 2, which is a reproduction of their classical diagram showing the variation of the height of the snow line in the Alps during the Pleistocene Period. From this diagram it will be seen that Penck and Brückner concluded that the snow line descended far down the mountains on four occasions, the limits reached each time being practically the same, namely, about 1,500 meters (4,000–5,000 feet) below the present snow line. They gave the names: Gunz, Mindel, Riss, and Würm to the four glacial epochs. It will be noticed that the four glacial epochs occur in pairs—the Gunz with the Mindel and the Riss with the Würm—with a rather longer interglacial epoch between them.

There is no certain evidence that the history of the ice worked out in the Alps applies to other parts of the world; but meteorological considerations make it very improbable that there were different glacial histories for each part of the world; and as the evidence of glacial and interglacial epochs has been found wherever the glacial history of a country can be worked out in detail, one is justified in concluding that these epochs occurred simultaneously as the result of a world-wide cause.

This conclusion is becoming more and more accepted by glaciologists as they work out the sequence of the glacial epochs in their own regions, and a meteorologist cannot accept any other conclusion. In the sequel, therefore, we shall consider that the glacial history of the Alps is representative of the glacial history of the world as a whole.

The advance and retreat of the ice must have been accompanied by large variations in the climate. When a country such as Great Britain was invaded by an ice sheet, the climate must have been that of the polar regions today, and the fossils of plants and animals leave no doubt that such was the case. The climate during the interglacial periods, however, is much more interesting and unexpected. One would not have been surprised if the climate during the temporary retreat of the ice had remained cold and unpleasant. The evidence however, is quite clear that in some, if not all, the interglacial epochs, the climate became warmer and more genial than today. At Hötting, in the Alps near Innsbruck, fossil leaves have been found of a rhododendron which grows today only in Portugal and the Caucasus, where the temperature is higher and the rainfall greater than it now is in Hötting; in the rivers of Europe (including the Thames) the

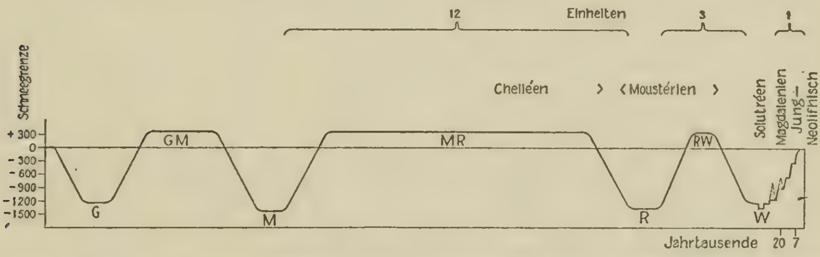


FIGURE 2.—Penck and Brückner's diagram of height of snow line in Alps during the Pleistocene ice age.

shells of fresh-water mollusks are found which now survive only in rivers such as the Nile, the temperature of which is 10° C. higher than that of the European rivers of today; and on the coasts of Holland and Denmark, beds of sea shells were deposited containing species 18 percent of which today only occur south of the Bay of Biscay.

There is still considerable controversy as to which of the interglacial epochs these finds should be referred; so that we do not know whether all the interglacial epochs had warmer and wetter conditions than are experienced today. But there can be no doubt that in one or more of the interglacial epochs the climate not only returned to present-day conditions but also became warmer and wetter.

Outside the areas which were invaded by the ice—the so-called glaciated regions—we must look to other records than those of ice to give us information regarding the changes of climate which occurred

there during the advance and retreat of the ice. In nonglaciated regions it is difficult to find traces of changes of temperature; but changes in rainfall leave clear records in river deposits and in the levels of lakes with small or no outlets. From such evidence there is no doubt that there were long and pronounced periods of heavy rainfall during the Pleistocene Period in practically all parts of the world.

In North America the Great Basin, which is now an arid, sandy desert, was full of water, and the small existing intensely salt lakes were vast sheets of water to which the names Lake Bonneville and Lake Labontan have been given. According to Gilbert and Russell, these lakes were twice filled during the Pleistocene Period, thus indicating that in North America there were two pluvial periods.

Wayland has reached the conclusion that in Uganda there have been two pluvial periods, one near the beginning of the Pleistocene Period and one toward the end; between these two pluvial periods the climate was much drier than it is today. Huzayyin has also recognized two major pluvials during the Pleistocene in southwest Arabia.[2]

Pluvial periods were not confined to tropical and subtropical regions, for in the Swanscombe Gravels we have evidence of a much greater Thames than exists today. The *Corbicula fluminaris* contained in these gravels show that they were laid down during an interglacial epoch when the temperature was considerably higher than at present.

Practically all deserts such as the Sahara, Libyan, and Kalahara show signs of water action in relatively recent times, and many of them are littered with the flint tools of prehistoric man, showing that in the latter half of the Pleistocene Period they supported sufficient animal life to make them good hunting grounds.

It is probably too early to say definitely that in all parts of the world there were two pluvial periods, but the evidence is very strong, especially in North America and Africa.

The climatic conditions during the Pleistocene Ice Age may be summed up as follows:

The Pleistocene Ice Age did not consist of a simple advance and retreat of the ice but of a sequence of glacial and interglacial epochs. Based on observation in the Alps, there were four glacial epochs separated by three interglacial epochs. During some at least of the interglacial epochs the climate was warmer and wetter than today. In regions not subjected to glaciation there is evidence of two great pluvial periods, one early and one late in the Pleistocene Period, separated by a long interval during which there was even less precipitation than at present.

[2] Nature, vol. 140, p. 513, 1937.

CAUSE OF THE PLEISTOCENE ICE AGE

A very large number of theories have been propounded to explain the cause of the ice age. It is becoming more and more generally accepted that no change located in the earth itself—such as a change in the distribution of land and water—or in the earth's atmosphere—such as a change in the amount of carbon dioxide or volcanic dust—can explain the sequence of climatic changes associated with the Pleistocene Ice Age, and we are being thrown back onto changes outside the earth. The most obvious source of climatic change would appear to be solar radiation. This seems such a simple solution. If we assume that the sun's radiation can change, all climates would appear to become possible; an ice age would be produced by reducing the radiation and a warm period by increasing it. Unfortunately, things do not go in this simple way. As the result of a study which I made a few years ago to find what happens to the solar radiation when it falls on the earth, and how the earth returns to space the energy which it receives from the sun, I was led to the conclusion that the last ice age was not caused by a decrease of solar radiation but by an increase. I must now try to explain this paradox.

The sun sends out a stream of energy which we call sunshine. The earth intercepts a quantity of this energy which on absorption warms up the surface and the atmosphere. If the earth had been a "black body" it would have warmed up to a temperature, which can be easily calculated, when it would have emitted just as much radiation as it received from the sun. In this way the temperature of the earth would have increased and decreased with an increase and decrease of the solar radiation. One of the first results of my investigation was to show that the earth does not react to changes in solar radiation like a "black body." I was able to show that if the solar radiation were to increase, the temperature of the earth's surface would not increase to anything like the extent that one would expect from the increase of solar radiation; but that the cloud would increase and return the greater part of the additional solar radiation without warming up the surface of the earth.

In this way the balance between the incoming and outgoing radiation is maintained more by the amount of cloud than by the temperature. In present conditions just about half the sky is covered by cloud; the amount is slightly different in the different latitudes, but not to any large extent. The clouds appear bright because they reflect the sun's light. The light which the clouds reflect cannot be used to warm up the earth; it is just returned to space, and to that extent the solar radiation is reduced. The amount of solar radiation returned directly by the clouds has been measured and proves to be 43 percent of the total incoming solar radiation. That is, nearly

half the solar radiation which reaches the earth is intercepted and returned by the clouds without taking any part in warming up the earth.

We will now consider what happens to the radiation which reaches the earth. Because of the shape of the earth, more solar radiation falls per square foot on the surface at the Equator than at the poles. The Equator is therefore maintained at a higher temperature than the poles. This difference of temperature causes differences of pressure in the atmosphere, and a circulation of air is set up between the Equator and the poles. This is called the general circulation of the atmosphere; and all winds ultimately can be traced back to differences of temperature, mainly those between the Equator and the poles.

In the course of time the atmospheric conditions reach a steady state with a certain temperature distribution, a certain amount of air motion, and a certain amount of cloud, which combined are just sufficient to cause a balance between the incoming and outgoing radiation.

Now let us consider what would be the effect of increasing the solar radiation by a specified amount. At first the increased radiation would reach the earth's surface and warm it up, but on account of the shape of the earth the Equator would be warmed up more than the poles. Hence, the difference in temperature between the Equator and the poles would be increased and this would lead to an increase in the general circulation of the atmosphere. The increased temperature and the increased wind cause an increase in the amount of water evaporated from the oceans. This increased water in the atmosphere leads to greater formation of cloud and, as the precipitation must equal the evaporation, to an increase in precipitation also.

The increased cloud, however, reacts on the solar radiation and reflects an increased proportion of it. The final state is a new balance between the incoming and outgoing radiation produced mainly by the increased amount of cloud, the only temperature change being that necessary to produce the greater amount of cloud.

Different parts of the world will be affected differently by these changes. In equatorial and temperate regions where the precipitation all falls as rain, the effects of increasing the solar radiation are simple: there is a slight increase of temperature and a general increase of rainfall. Thus the most important effect of increasing and decreasing the solar radiation is to increase and decrease the precipitation, and the two keep step with one another; a period of increased solar radiation is always a period of increased rainfall and vice versa.

When, however, we approach the poles, where the precipitation may be either in the form of snow or rain, the conditions are much more complicated and must be studied in more detail.

Let us fix our attention on a region where at present the summer temperature does not rise above the freezing point, so that there is little or no summer melting of the ice—the Antarctic is such a locality. Now let the solar radiation increase. In consequence, the precipitation and the mean annual temperature both increase, as indicated by curve I of figure 3. At first all the precipitation is in the form of snow, but when the summer temperature approaches the freezing point—say, at *A*—some of the summer precipitation falls as rain. Curve II represents the annual snowfall, and as the radiation increases beyond the point marked *A* the curve for snowfall falls increasingly

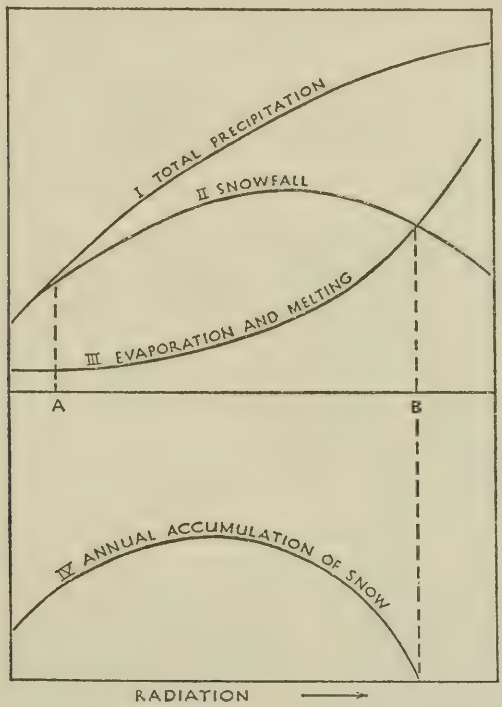


FIGURE 3.—Effect of increasing radiation on precipitation and accumulation of snow.

below the curve for the total precipitation. Curve III represents the evaporation and summer melting combined. At first there is no melting, only evaporation, but after *A* melting becomes more important, and at *B* the loss of ice through evaporation and melting equals the total snowfall. Curve IV in the lower half of the diagram represents the annual accumulation of snow; it is obviously the difference between curves II and III. At first, the annual accumulation of snow is small; as the solar radiation increases, the accumulation of snow increases until it reaches a maximum, after which it rapidly decreases, owing to the rapid increase in the amount of melting.

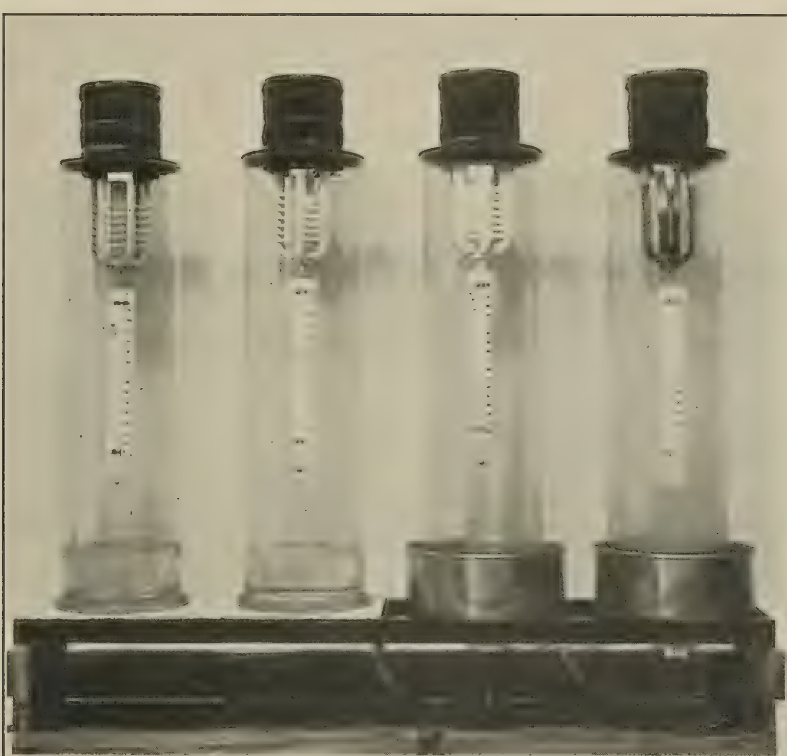
Finally, in spite of the greater total precipitation and large annual snowfall, the melting is so great, especially in the summer, that no accumulation at all takes place.

Although it may seem strange that an increase of temperature can produce increased glaciation, it may be demonstrated by a simple experiment. In four identical glass jars (pl. 1) each containing a layer of water in the bottom and a metal vessel at the top which can be cooled by solid carbon dioxide, the water at the bottom represents the Equator and the metal vessel at the top the polar regions. One jar (second from the left) contains water at the temperature of the room and there is an appreciable deposit of ice at the top. By adding ice to the water in the vessel to the left, equivalent to lowering the equatorial temperature, the deposit of ice at the top is much reduced. The water in the third vessel has been warmed by a small gas jet, and the effect of the heating has been greatly to increase the deposit of ice. In the fourth bottle the temperature has been raised still higher, with the consequence that the ice has almost entirely disappeared by melting.

These four bottles can be regarded as representing increasing radiation as shown in figure 3. The first bottle has a low temperature (little radiation) and the ice deposit is thin, corresponding to *A* on the diagram. The second bottle has a higher temperature (more radiation) and therefore corresponds to a point to the right of *A* on figure 3 and shows a greater accumulation of ice. The third bottle represents the conditions where the ice deposit reaches its maximum, and the fourth bottle represents some point beyond *B* where the melting and evaporation exceed the deposit.

The conditions represented by figure 3 and the experiment apply to the polar regions and high mountains. At first an increase of solar radiation causes an increased accumulation of snow and ice in spite of increased temperature. During this stage, ice sheets form and glaciers advance, giving rise to a glacial epoch. As the radiation increases still further, the ice melts away and we have overcast skies and much precipitation but no ice accumulation. When the solar radiation decreases, conditions are reversed and the whole sequence is gone through in the reverse order.

Figure 4 has been prepared to show the sequence of changes of ice and meteorological factors when the solar radiation makes two complete oscillations. The abscissae represent time increasing toward the right. Curve I represents two complete cycles of solar radiation and curve II represents the mean temperature of the world as a whole. Curve III is the curve of precipitation and therefore follows directly the curve of solar radiation. Curve IV is the curve of snow accumulation. As drawn, it shows some accumulation at the minima of the solar radiation, but a complete disappearance of the accumulation



EXPERIMENT TO SHOW HOW INCREASE OF TEMPERATURE CAN PRODUCE INCREASED GLACIATION.

Temperature at bottom of bottles increases from left to right.

owing to increased temperature at the maxima of the radiation. The ice which accumulates year by year in the specified area must escape; if the area is a mountain top, the escape will be by way of glaciers; if it is a polar cap, the escape will be by an ice sheet spreading over the surrounding country. In either case the ice is transported into regions where the melting is greater than the snowfall, and the greater the annual accumulation the farther will the ice penetrate, down the mountain side if a glacier and into lower latitudes if an ice sheet. Curve V shows the advance and retreat of the ends of the glaciers or of the front of an ice sheet.

Examining the last curve, we see a close resemblance to Penck and Brückner's curve for the height of the snow line in the Alps (fig. 2). In each there are four advances of the ice. The advances are arranged in pairs, with short interglacials between the advances in the pairs, and the pairs separated by a longer interglacial. This arrangement comes from the fact that there are two glacial epochs for each maximum of the solar radiation. The interglacials have different climates according as they occur at the maximum or a minimum of the solar radiation. The former are warm and wet and the latter are cold and dry. We are at present approaching a minimum of solar radiation. In consequence our rivers are smaller and our temperature lower than they were in the last interglacial. We now see why there were only two pluvial periods in nonglaciated regions for the four glacial epochs in polar regions and on mountains. If the theory is correct, the last interglacial—the Riss-Würm interglacial—was a warm one, and to it the evidence for a warm wet climate which I have described above should belong.

Thus we see how two oscillations of radiation have produced in nonglaciated regions two pluvial periods, and in glaciated regions four glacial epochs separated by three interglacial epochs, two of which were warm and wet and one cold and dry. If the theory is correct we are now living in a cold dry epoch owing to the decrease of solar radiation from its last maximum. If the solar radiation again increases, there will be another glacial epoch and our epoch will become a second cold dry interglacial.

An obvious objection to the explanation of the last Ice Age which I have given above is that with their present temperatures no amount of precipitation would result in the formation of an ice sheet over England and Scotland and still less over Ireland; yet we know that such ice sheets did exist. The objection is still stronger when it is remembered that the theory requires the increase ofprecipita tion to be accompanied by an increase of temperature.

There is another problem which has puzzled everyone who has studied the cause of the Ice Ages. If we plot on a circumpolar map

the limits of the ice sheet, we find that the area covered by the ice was not concentric with the North Pole. It extended much farther south over Europe and the east of North America than it did over Asia and the east of America; in fact the center of the ice sheet was in the middle of Greenland, 20° of latitude from the Pole.

The answer to both these problems is the same and gives strong support to the correctness of the theory. If the area around the North Pole were land instead of sea, we should have at the Pole a great ice sheet, similar to that over Greenland and the Antarctic,

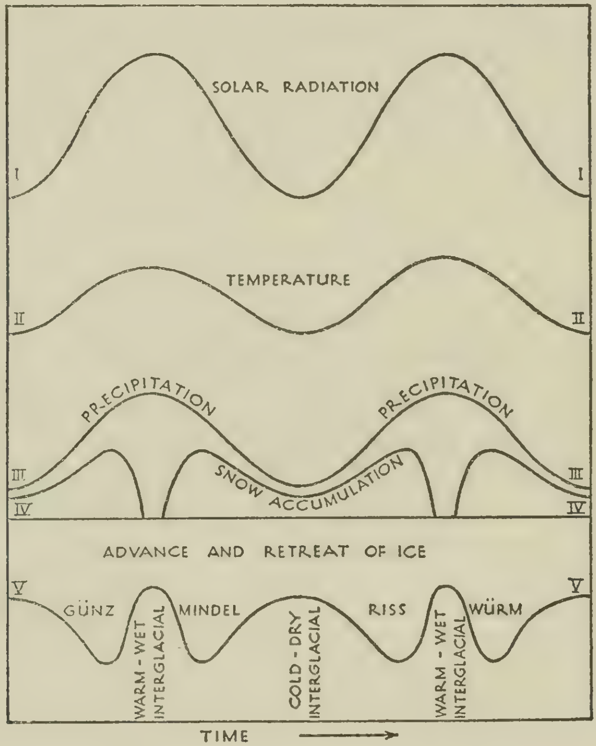


FIGURE 4.—Effect of two cycles of solar radiation on glaciation.

rising many thousands of feet above sea level. With increased precipitation this ice cap would increase in height and extent and grow symmetrically about the Pole. With the present distribution of land and sea such a north polar cap is not possible. The ice which forms in the Arctic Ocean during winter breaks up in the summer and a certain amount escapes into the North Atlantic Ocean. At the maximum of a glacial epoch when the coasts around the Arctic Ocean were under ice, there would be a great flow of ice throughout the year into the sea. The whole Arctic Ocean would become packed with ice which would have to find an outlet somewhere. The Bering Strait between

Asia and America is both narrow and shallow, and no appreciable amount of ice would escape that way. There was always, however, a wide, deep connection between the Arctic Ocean and the Atlantic Ocean between Greenland and Norway. Through this passage icebergs and thick pack ice would move southward, filling the North Atlantic with ice and lowering the temperature.

Figure 5 has been drawn to illustrate this. The ice-covered area has been stippled and it will be seen at once that this area is not concentric with the Pole. The flow of ice on the land is shown by thin

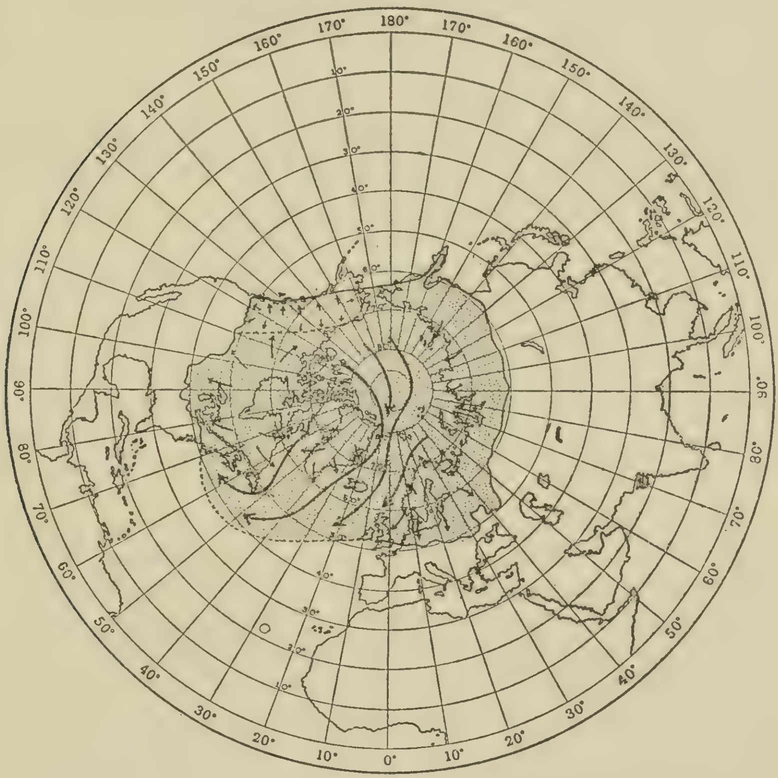


FIGURE 5.—Lines of flow of ice: Thick arrows, floating ice; thin arrows, land ice.

arrows. Ice flows into the Arctic Ocean from the northern coasts of America and Asia, and moves, as shown by the long thick arrows, into the North Atlantic, where it is replenished by ice from Greenland and Norway, and a stream of ice passing down Davis Straits joins it to the south of Greenland. The whole of the North Atlantic was filled with ice.

These conditions would have far-reaching effects on the climate of the British Isles and the adjacent parts of Europe. In the first place the Gulf drift would no longer exist, so that instead of the western

coasts of Europe being washed by relatively warm water they were washed by cold seas dotted with ice. In the second place the Icelandic depression would either cease to exist or would be displaced to the south, so that the warm southwesterly winds to which we owe our mild climate were replaced by cold northwesterly winds. With these large changes there is no wonder that ice sheets formed on the British Isles. On the American coast the winds would be northeast and drive the ice-laden water on to the American coast. Thus glacial conditions extended far to the south on both coasts of the Atlantic Ocean. As there was no corresponding flow of ice into the Pacific Ocean, there was no similar glaciation of the Pacific coasts.

Thus the glaciation of the British Isles and the unsymmetrical position of the ice sheets relative to the Pole were both due to flow of ice from the Arctic Ocean into the North Atlantic. If this connection had not existed, the distribution of the ice would have been quite different.

SOIL EROSION: THE GROWTH OF THE DESERT IN AFRICA AND ELSEWHERE [1]

By Sir Daniel Hall, K. C. B., M. A., D. Sc., LL. D., F. R. S., M. R. I.
Director of the John Innes Horticultural Institution; lately Chief Scientific Adviser to the Minister of Agriculture and Fisheries

[With two plates]

It is a commonplace of geology that the surface of the earth is constantly in motion—that our mountain ranges have taken shape and our river courses and valleys have been excavated by the simple agencies of rain, frost, and wind. But we are accustomed to think of these agencies as operating over long periods, geological rather than historic time. Even Darwin's discovery that earthworms can bury stones on the surface of pasture land at the rate of an inch in every 4 or 5 years came as a surprise. But in many parts of the world a much more rapid movement of the surface is going on, with serious economic consequences to the agriculture of the country—and it is this form of denudation, that we call soil erosion, with which I propose to deal tonight.

Usually we regard the soil as something particularly stable, but I want you to realize that this stability is almost wholly due to its normal covering of vegetation. By soil we understand the surface layer of relatively fine-grained material—sand and silt and clay, generally dark in color through the presence of humus—and traversed by the roots of the surface vegetation. As a rule the soil proper is not more than 6 inches to a foot deep; below this the humus becomes small in amount, though there are a few "black soils," as in Russia or Manitoba, which are rich in humus to a depth of 4 feet or so, but these are uncommon. But what I would remind you of, even at the risk of being elementary, is that the fertility of land resides in this surface layer of soil. The humus supplies the nitrogen, which is the chief element of plant nutrition, and the phosphoric acid, of almost equal importance, is chiefly accumulated in the upper soil. It is a fallacy of old standing that the good earth lies below to be brought up by the man who will put his plow in deep enough. Nevertheless, there is great virtue in

[1] A lecture delivered before the Royal Institution of Great Britain at the weekly evening meeting, November 12, 1937. Reprinted by permission from the pamphlet of the Royal Institution.

deep cultivation, provided the topsoil is kept on top and the lower layers are only stirred and broken up.

This being premised, there is always a danger that if the cover of vegetation is removed the soil itself will begin to move under the action of either the wind or the rain. Rarely do we see these actions at work on a large scale in England; the climatic conditions are not favorable, for our rainfall is gentle and evenly distributed throughout the year, and our big winds are mostly associated with rain. It is in semiarid regions where long periods of drought may be followed by torrential rains that soil erosion becomes an active danger. Still, I have known cases: some 40 years ago in the Lincolnshire Wolds near Louth an intense thunderstorm, such as is loosely called a cloudburst, broke over a steep hillside on the chalk, the grass covering of which had been broken near the top of the hill by a rabbit burrow. The rushing rainwater got an entry there and in less than an hour had stripped the hillside down to the bare chalk. I have known a similar thunderstorm in Kent to remove 3 feet of soil from the hop garden, leaving the plants with their network of roots suspended on the superstructure of wire and string. I have again known a barley crop on the Surrey sands blown into the hedge after it had become 2 or 3 inches high. But these are rare instances, which serve only to illustrate the risk of erosion in countries where our total rainfall of a year may be concentrated into 1 day, or where scorching winds may obtain a run of 1,000 miles over the steppe.

The earliest cases of erosion to be noticed are those which follow deforestation in regions where the mountains in which the rivers take their rise are below the permanent snow line. In such countries, typically in the eastern Mediterranean—Calabria, Greece, the greater part of Asia Minor—the natural sequence is forest on the higher slopes where the rainfall is greatest, passing into upland meadows as the slope grows less and finally into river meadows as the river nears the sea. There is no evidence in support of the belief that forests increase the rainfall of a country, indeed, by the transpiration from their leaves they must reduce the total amount of the rainfall retained by the soil, but they serve as its regulator. The spongy soil below the trees, rich in humus, absorbs the rain as it falls, whereby it reappears later in the springs and furnishes the watercourses and rivers when the rainy season has passed. But too commonly the forests have been cut down without any regard to their regeneration; not only has the maximum of timber been cut out but there has also been the desire to extend the grazing. Grazing is all very well again if regulated, but unfortunately in these Mediterranean countries goats are among the chief grazing animals. It is no accident that old tradition has represented the Evil One with the hoofs of a goat, for of all animals the goat plays the devil with land. Hungry goats will eat anything that grows; they

destroy every seedling tree as fast as it gets its head up; they complete and extend the destruction the woodcutters have begun. At the same time, with their sharp hoofs they break the surface of the soil, in other places they tread hard paths down which the rain begins to run with gathering volume and velocity. In a very short time during the rains gullies begin to form as the soil is washed downhill; year by year the gullies extend and bite deeper into the earth, until in no long time—a generation or two—the hillsides that had been forest and upland meadow get bared down to the hard infertile subsoil or to the rock itself. Nor does the damage end there; the rainfall, running off the bared hill country without a check, develops as a torrent lower down, attacking the meadows bordering its course. The earth also that has been washed off the hillsides is carried down to the plains where the rivers lose their velocity; there it deposits and turns the river into a chain of malarious swamps, it chokes it mouth, and destroys any harbor that was there. Such has been the history of much of the fairest land on the seaboard of the Levant; on the heights bare rock where once forest and meadow flourished, rivers that are torrents in winter and dry in summer, old seaports no longer accessible. The destruction of the forest was thus a major factor in the decay of Greece and Rome itself; it meant, in the first place, the loss of farming land and of the agricultural population which formed the backbone of the early armies of the republics. With the swamps came the spread of malaria, which again has been invoked as one of the great causes of the fall of ancient civilization.

Cogent as have been these lessons, they were not always remembered in the new countries opened up in the nineteenth century. Forests were destroyed greedily and indiscriminately, but the more evident consequences have been that the rivers became subject to violent flooding due to the sudden run-off in the rains, and dams and irrigation reservoirs began to silt up rapidly. The most spectacular form of soil erosion is that exhibited by the vast dust storms which in 1934 and 1935 especially swept over the United States east of the Mississippi. It was no new phenomenon, although before that time it had not been considered politic to talk about such a blot on pioneering enterprise in the Middle West. Locally a vast area, which included western Oklahoma, western Kansas, eastern Colorado, the Panhandle of Texas, and parts of Wyoming, was known as the "dust bowl." In 1934 it was estimated that on a single day 300 million tons of rich topsoil was swept as far away as the Atlantic. There is a story that in the diary of an old Nebraska doctor was found the entry: "June 14th. Hot as hell, wind 40 miles an hour, two Kansas farms go by every minute."

It is not the United States only that has been suffering thus from wind erosion; across the northern border the conditions leading to

wind erosion are repeated in Saskatchewan and Alberta (pl. 1). I have myself seen the soil on the move on the great plains, drifts of sand piled up against fences or any other obstruction, choking the sunk roads, a most depressing phenomenon, especially when accompanied by swarms of grasshoppers, smaller but little less destructive than the locusts of the Old World. We have similar accounts from Central Asia of the dust storms and encroachments of drifting sand in the neighborhood of Bokhara. It has been stated that only the Caspian Sea has prevented the march of the sand into the fertile regions of the lower Volga. But of recent years the Soviet engineers have discovered a means of getting a cover of vegetation again and so stabilizing the soil.

The causes of this terrible wind erosion are easy to discern. It arises only in comparatively arid districts where the rainfall is below the 20-inch level, and (in America, at any rate) where the fundamental subsoil is of a rather sandy type—a recent glacial drift. Before white settlement these regions were clothed with grass and were the natural home of the buffalo. Some of the land was good grazing, with a fair depth of black soil rich in humus, but in the drier parts the sod was thin and there were only a few inches of soil. The black soil regions were fertile and were the first to be broken up; the poorer land was kept for ranching, healthy for either cattle or sheep if not too closely stocked. The plow, however, began to encroach upon these thin soils, with great rapidity when prices of cereals went soaring up from 1917 onward. At first all went well, for the cultivation began in a cycle of good rainfall seasons, and there was some stock both of humus in the soil and of accumulated rainfall below. The system of farming that prevailed was of a wasteful type, a succession of cereals, or wheat and maize with occasional timothy grass in the better lands of the Middle West, but wheat and oats year after year in the Canadian Northwest. The straw was burnt, no stock was kept; a few years of such mining in the soil with no recuperative crop was enough to exhaust the limited stock of humus. Then years of drought came when the original subsoil reserve of water had been used up and the light soil, no longer bound together either by vegetation or humus, began to drift in the fierce winds that sweep over those great plains. The plow had destroyed the binding power of the soil; the wind is then able to remove the whole of the fertile top layer of soil and leave nothing but the denser subsoil which is too infertile to carry a crop. Nor has it been the case that the good soil is merely transferred from one farm to the next; as a rule in Canada it has been swept right away into the Great Lakes or the barren lands to their north, or even into the Atlantic itself.

It is sometimes represented that agriculture has been public enemy No. 1, as destructive an exploitation as lumbering and more rapid in

its action. But what the pioneer opening up a new country practices is rarely agriculture; he breaks up the virgin surface, and not uncommonly expects to move on in a few years and make his profit out of enhanced land values. It is imperative for him to grow nothing but immediate cash crops, and the process on much of this western land was of the crudest. Often the farmers, once their crops had been lodged in the elevators, turned the key in the door and went off to California until seedtime came round in the spring. There was no livestock on the farm, no garden round the gaunt frame house, the farmer seemed to have little thought of making a home, but only of cashing in some crops and then moving on. The pioneer works with a feeling of infinity at the back of his mind; there is always more land somewhere. As one of them is reported to have said to a United States Soil Conservation officer: "I have run through two farms, and I'm getting out of this. You can't teach me nothing about farming." Without doubt much of the poorest of this land ought never to have been plowed, even in boom times; once the crust has been broken it becomes a sort of running sore, always eating into the land on its margin. As a ranch under its natural vegetation it had a modest productive value, and to that use it must return. But the process of natural regeneration will take time, a generation perhaps before vegetation will creep over the barren subsoil to fix the sand and build up some reserve of humus. Its productive capacity is too low to pay for fertilizers, but a few plants can be introduced which will colonize the waste and begin to restore fertility. In the better land which can be made to retain its productivity under crop, a conservative system of farming must be introduced in which the cereals will alternate with a cover crop, partly leguminous, which when grazed will both add humus to stabilize the soil and collect nitrogen from the atmosphere. We know that many European soils have been cultivated for 1,000 years or more without showing any decreased production, by making use of the power of certain bacteria to fix nitrogen. In China, too, that mother of all the arts of life, intensive cultivation has been maintained for 2,000, 3,000, perhaps even 4,000 years without soil erosion or loss of fertility.

Of recent years improved methods of cultivation have been introduced to minimize the danger of soil drifting. Since it is inevitable that at certain seasons of the year, indeed in dry farming areas throughout a whole year, the soil should be cultivated while bare of a crop, the practice has been introduced of dividing the land into strips, the bare land alternating with land under crop in place of the former large areas under the same treatment. Thus the incipient soil erosion under the wind is checked before it can proceed far, and a very efficient measure of protection is attained.

114728—39——21

One other major work of reconstruction is needed, though it is being taken in hand on a large scale in the United States, and that is the establishment of shelterbelts to break up the fierce winds that rage over these open, treeless spaces. It is not an easy matter to get trees started, especially in the north in Saskatchewan and Alberta, where the range of species that will stand up to the extremes of climate is limited, but a certain number of suitable species have been found. Besides the regional planting of cross-country belts, farmers are being taught to protect their own holdings.

So far I have only been describing to you cases where the eroding agent is the wind on the flat plains, but erosion by rain is even more common wherever the cultivated land is set on any slope and the rains are heavy. The danger does not lie in a large annual rainfall; some of the worst destruction is wrought in regions where a low total is concentrated into short intense spells. A high rainfall will, as a rule, generate such a forest vegetation as will protect the soil, though as tea planters in Ceylon and Assam have found to their cost, any piece of cultivated soil on a slope is in danger of erosion, sometimes a slow continuous removal of the good soil, sheet erosion, sometimes a catastrophic wash-out by gullying. Preventive measures are now well known; terrace the worst slopes and cultivate along the contour lines so as to avoid setting up watercourses. The object is to get the soil to absorb the rain as it falls without giving it a chance to set up a run over the surface, but in bad cases it may be necessary to break the contour terraces at intervals with spillways which lead accumulated water into an unobstructed drain or watercourse. Alternatively where washing is severe, occasional belts of unplowed vegetation should be left, in order to break any run-off that may have been set up. By such grading of the slope, coupled with the growth between the bushes of a temporary crop of some leguminous plant, which can be dug in so as to add to the stock both of nitrogen and humus, the tea planters of Ceylon have been able to check soil erosion even with the excessive rainfall that often prevails there. It should be remembered that such a system of contour terracing has been practiced in China from time immemorial.

But wherever torrential rains occur there is always the danger of starting gullies in bare soil. We can see the process operating in this country when rain falls on any spoil bank or bare cutting; as soon as the rate of fall becomes sufficient to cause an actual flow of water at any spot, it acquires an excavating power and begins to cut a channel in the loose earth, a gully which not only enlarges itself by the undercutting of its banks but tends to eat its way backward. Gullying can be initiated either by careless management of cultivated soil, or on grassland by overgrazing, which bares the surface. Even before actual overgrazing sets in, both cattle and sheep will

tread bare tracks along which streams will begin to flow during the rains and to acquire sufficient velocity to eat into the soil. In however small a way such gullying starts, if it is not checked it extends itself from season to season, both fanwise and by eating uphill, until eventually, by a sort of geometrical progression, the large area may become impassable to man and beast. Though agriculture generally is indicted as the initiator of erosion, more properly it is the recklessness or the want of foresight in man that should be blamed.

In a recent book, Rich Land, Poor Land,[2] there is an account of a gully with a history:

> The land fell away almost sheer for 200 feet. We stood over one of the gully's arms and far down caught a glimse of the central basin. The guide took up the tale. "Do you know what started him? A trickle of water running off a farmer's barn about 40 years ago. Just one damn little trickle, and now a third of the county's gone—40,000 acres."

One should realize that in certain regions and climates the soil is so lacking in any binding power save its skin of vegetation that all handling of the soil has to be watched with the same sort of communal care that is accorded to fire risks in a crowded city.

Nor is agriculture the only culprit in initiating the destruction of the vegetation. At a place called Ducktown in Tennessee, a gullied area has been created through the destruction of the vegetation by sulphur dioxide from a copper smelter. "In a great circle about the smelter, measuring perhaps 10 miles in diameter, every living thing had been destroyed by the sulphur fumes."

The loss of land by soil erosion is not the only loss the community suffers. The soil that the rain starts moving reaches the rivers and has to find a resting place somewhere. It is in regions liable to erosion that irrigation becomes of so much importance, and dams are thrown across the rivers to store the floodwater of the rains. But no one had foreseen what masses of sand and silt would begin to choke the reservoirs when erosion was going on at the headwaters. I quote from the same book, Rich Land, Poor Land:

> Elephant Butte Dam was built by the United States to guarantee New Mexico's quota of water "forever." "Forever" will end in a few years if the Rio Puerco, which chiefly ravishes the Rio Grande, is not controlled. Every flood season it pours 9,000 acre-feet of silt into Elephant Lake.

Even if there are no dams, the eroded material is deposited on the river flood meadows of the lower valley, a fertilizing deposit as long as the topsoil is coming down, but as gullying proceeds the river is laden with larger quantities of the sterile subsoil material. The bed of the river steadily rises through accretions of silt, and the flood banks, like the levees of the Mississippi, have to be raised to keep the

[2] Chase, Stuart, Rich land, poor land, McGraw Hill Publishing Co., New York, 1936.

floodwaters back. You will have noticed how the last Mississippi flood of 1936 was the wildest and most dangerous of any in the history of the river, notwithstanding all the protective measures that had been carried out, simply because the lower river is being raised more and more above the level of the surrounding country.

A large amount of work is now being done in the United States to control gullying and to reclaim the devastated land. In the early stages gullying can be checked by throwing dams across the gash, dams which may be timber or concrete or just bushes, alive or dead, anything that will check the rush of water and cause the sediment to begin to accumulate. Even more effective has been the introduction of rapidly growing vegetation, e. g., Kudzu (*Pueriana Thunbergiana hirsuta*), a creeping leguminous plant, which not only checks the flow of water and filters out the silt but binds the earth and stops further washing, and at the same time gathers nitrogen and begins to build up a new soil. The Soil Conservation Service in the United States is bringing into play all the resources of science and engineering to repair the damage which has been inflicted upon the land of the United States by hasty exploitation. I would instance again the Civilian Conservation Corps, that inspiration of President Roosevelt's, who in 1932, when the youth of America found no prospect of employment of any kind on leaving school or college, gathered some 300,000 of them into a service and set them to work to clean up the countryside. They were turned on to fire-prevention work in the forests, to checking erosion, to road making and vermin destruction in the national parks, to various forms of reclamation and salvage work—the corps itself being the most magnificent piece of human salvage this generation has known. One cannot but think that it would be of value to our population if all our young men could be conscripted for 6 months of their life to carry out public work for the improvement of our countryside.

The examples of erosion I have been putting before you are all due to unthinking exploitations of the soil by civilized men. I now want you to consider what is going on in Africa under native systems of farming. To begin with, we must realize that none of the African tribes had arrived at what may be called a "conservative" system of farming, such as has been the custom of European races and of many Asiatics from the earliest times of which we have record. European farming is essentially founded upon a rotation of crops in which a recuperative legume like clover or beans finds a place, and in which again livestock play their part in converting into manure such parts of the crops, like straw, as are not available for human food, together with grass and other rough fodder from the uncultivated land. The African tribes are still in the more primitive stage of "shifting culture." The cultivator is allotted a particular plot in the area of jungle or

bush belonging to his clan; this he, or rather his wives, clear, perhaps burning off the timber before putting in the crops—millet and now maize, cassava, yams, etc. In 2 or 3 years the soil begins to become exhausted or weeds become intractable, whereupon the plot is abandoned and a new piece is taken up. The abandoned plot soon covers itself with the natural vegetation and in course of time, perhaps 10, perhaps 30 years, recovers sufficiently to be ready to take into cultivation again. Thus the tribe requires many times as large an acreage of land as is actually in cultivation at any one time, and if the tribe is increasing in numbers they will be eating pretty steadily into hitherto unoccupied grassland or forest. One other feature is of importance; the Bantu tribes who predominate in East Africa attach the greatest value to livestock, particularly to cattle. Cattle represent wealth and position, they are intimately bound up in tribal custom with the marriage ceremonies, indeed they enjoy a definitely religious status. They are the essential consideration that has to be tendered for a wife. But they serve little or no economic purpose. They are not eaten except ceremonially, by many tribes they are not milked, they are not beasts of burden, neither is their dung used as manure. Sheep and goats are in the same category, they are less sacred and less valuable, their only economic product is their skins for clothing. In one sense cattle are money, but they are also something more than *pecunia;* every native is anxious to increase the number he owns, for on that depends his credit in the tribe. Of course, there are other tribes like the Masai who are pastoralists, not cultivators, and who live largely upon animal food, in the case of the Masai upon milk and blood. These tribes maintain large herds of cattle and goats and shift their location seasonally with the grazing; what little cultivation goes on within their reserves used to be carried out by dependent men of other tribes. Nowadays, however, cultivation is increasing.

Consider the consequences—within this century British rule has maintained peace among the tribes, and with the cessation of raiding, numbers have been rising steadily. According to census returns, the native population in the Union of South Africa has doubled in the last 50 years; in Basutoland the estimated population multiplied fourfold between 1879 and 1921. In Kenya the annual rate of increase is estimated at about 1½ percent, which means doubling the numbers in 46 years, and similar estimates are made for the Nandi tribes in the Kavirondo, and for the Uganda population. These increases are, of course, not universal, for the Masai seem to be shrinking, as do the northern Nigerian tribes, where the spread of the desert has become marked. There are other cases of dwindling populations, some of which may be ascribed to maladministration without due regard to the interests of the natives.

The increase of human population has been accompanied by an even greater increase in the numbers of livestock, which in the old days had been effectively kept under by raiding. "What are you looking at?" said a district officer, who had climbed up to the crest of the great Nandi escarpment, to two old chiefs he found gazing down at the plain of the Nyanza. "Our cattle," was the answer, with a wave of the hand toward a settlement of one of the weaker tribes below. But with these checks gone, the animal population has outgrown the means of sustenance, and even in some districts is destroying the vegetation in uncultivated areas, which should be regenerating against their turn to be brought into cultivation. The Native Economic Commission of South Africa, reporting in 1932, stated: "With the exception of certain parts of Zululand and Pondoland, every native area is overstocked," and estimates that between 1918 and 1930 cattle increased from seven to seventeen hundred thousand, and sheep from two and one-fourth to nearly four million. The Kenya Land Commission, reporting in 1933, wrote: "Probably about 1920 the main stock areas of the native reserves had attained their optimum carrying capacity, and although fully stocked, were not overstocked. Since then the cattle population has, roughly speaking, doubled itself." Again of the Kamba reserve:

> Mr. Scott Little estimates that the reserve contains 190,000 cattle, with 57,000 calves, though he estimates its grazing capacity at no more than 60,000 head. There are also 260,000 goats and 150,000 sheep. A journey through the area east and south of Machakos reveals that over large stretches of hillsides vegetation has been almost wholly removed. The soil has been eroded down to the subsoil, and its removal will continue at an ever-increasing rate. On less steep slopes and on better land vegetation still persists; and though the Wakamba are primarily a pastoral tribe, patches of cultivation are in evidence. But even there grazing has been so persistent that the ground is all beaten down into little stock paths and has become in turn open to erosion.

I have been over this area and seen the hillsides bared down to the yellow, red, and purple hardpan, where within the memory of the headmen with whom we talked there had been useful grazing.

A Basutoland report states:

> Overgrazing has so far failed to destroy the grazing on the lower levels, up to, say, 7,500 feet, but above that level the concentration of stock driven out from the lower levels has resulted in the replacement, over some hundreds of thousands of acres, of the grass by the almost inedible *Chrysocoma*, commonly known as "Bitter Karoo."

Mr. Hobley, giving evidence about Tanganyika, said: "The native occupier, if space permits, moves on, leaving exhausted soil and desert behind him." Professor Stebbing has uttered strong warnings of the encroachment of the Sahara upon northern Nigeria, due to shifting cultivation and overstocking in the forest. Major Grogan put the matter brutally when he said before the Kenya Land Commission:

"The African people have never established a symbiotic relationship with land. They are, in the strict scientific sense, parasites on the land, all of them;" and in another place he speaks of flying over central Africa and picking out the eroded areas by their color.

These instances will suffice; over a large part of Africa—the eastern side from the Abyssinian frontier down to the Cape, Uganda, and parts of Nigeria, everywhere indeed except in the tropical rain forest of the western seaboard and interior—conditions are such as render erosion by washing a danger. Under cultivation the humus of the soil rapidly becomes exhausted, the climate produces recurrent periods of drought broken by rainfalls of fierce intensity. You have further a native population practicing a destructive form of agriculture and keeping a vast uneconomic head of stock, including the devastating goat in large numbers; they are eating rapidly into such forest areas as are left open (pl. 2). Small wonder that famine is never far away from some of the tribes, that the major political issue between native and white man is the cry for more land. Yet even if there were more land to give, the day of reckoning would only be deferred, the new land would only be eaten up in its turn; the native must either change his methods or limit his numbers. Indeed the situation has even now gone so far that from time to time the Government has to import food to save a tribe from starvation, and the problems of native unrest and land hunger begin to press on the white community. African soil was never rich nor presented that reserve of easily exploited fertility that has been the wealth of both North and South America; it is also, as no other country, a reservoir of diseases of man, animals, and plants. Soil erosion has been developing for years without attracting very much notice, and has now reached the stage when the growth of the desert may speed up catastrophically.

It is but recently that the dangers of erosion in Africa have come to be realized. When I was in Africa in 1929 I saw how contour cultivation and recuperative grassland was being introduced into the farming of the Cape Province, and the Drought Investigation Commission of 1923 had references to erosion. The problem of overstocking was preeminently before me on the Kenya Agricultural Commission, but the widespread extent of erosion was only made evident in later reports, such as that of the Native Economic Commission of South Africa in 1932, the Basutoland Enquiry, and the Kenya Land Commission of 1933. The Basutoland report shows that the administration had begun to take measures for the regeneration of wasted areas, but now it is evident that all the African colonies have become erosion conscious, as may be seen from Sir Frank Stockdale's report on his recent tour through Africa. Thanks to him, I shall be able to show you a number of photographs of the methods that are being adopted.

Much yet remains to be done before the arrears of years of misuse of the soil can be repaired and before the native population can be educated to systems of farming which will maintain the fertility of the land. Not only have drastic changes in native custom to be brought about, but in many cases expenditure is called for which can hardly be found within the limited resources of the particular colony.

The regeneration of wasted areas must begin with closing them for a time to grazing, so as to allow the return of natural vegetation; if the land has not been very badly denuded, recovery is rapid; but in some cases it may be necessary to introduce specially useful plants, like the stoloniferous grasses so characteristic of South Africa. A certain amount of minor engineering is needed to check run-offs and dongas by dams or plantations. Some of the photographs I have show how successful such measures have been at no great cost. Measures to deal with the invading weeds like *Striga* in central Africa or the *Chrysocoma* of the south are still lacking. At the same time cultivators, both natives and white settlers, are being taught the virtues of contour plowing and planting, and of vegetation strips in cultivated land to break up run-off.

Such measures, however, do not touch the major cause of erosion—overstocking. There legislative action is necessary to compel a reduction in the head of stock. The native chiefs giving evidence before me on the Kenya Agricultural Commission agreed that Government regulations to this effect would be carried out, but that without an ordinance the chiefs themselves would be unable to enforce restriction. However, the drastic culling that is called for must be done by way of purchase, and since the animals which would first be drafted are practically valueless for food, one or more meat factories would be required to turn the carcasses into manure and then into successively better products as the quality of the culls improved. One such factory was in operation in Tanganyika, from the working of which one learned that the initial capital requirement is large and that in its early years the enterprise is not likely to pay its way. But a reduction in the numbers of cattle or sheep to one-half or so would not only relieve the pressure on the land, but would give the native owners some chance of improving quality both by selection and better feeding, whereas at present numbers alone are valued. Education should also proceed to induce the natives to use cattle economically for milk or meat and for traction, or at least to sell them for food. One cannot, however, get away from the fact that forcible limitation of the head of stock a man may hold is a grave interference, not only with tribal custom but also with the dignity of individuals. I am still attracted by the idea of a special

token currency for the purchase of native livestock, something that might be made a visible display of wealth and status.

Even more fundamental must be the education of the natives to adopt a conservative system of farming—a rotation that would include leguminous crops and so help the native dietary as well as restore nitrogen to the soil. Compost making is another method of maintaining fertility which is being taught to the natives. The African cannot increase, cannot even maintain, his present numbers unless he learns how to use his plot of land so that it will continuously produce food. Demonstrations have shown how it can be done, but it will need both a strengthening of the agricultural staff and years of effort before the improved practices are taken up.

But it is difficult to speak temperately of the urgent need for effort in this direction on a large scale. Many of the tribes are on the verge of starvation, the desert is growing apace, and as the cropping or grazing area shrinks, the pressure upon it becomes greater and destruction proceeds at a compound-interest rate.

The responsibility for action lies not only on the colonial governments but on the British Government itself. It has declared itself trustee for the native populations; it must save them from themselves. Other nations are demanding colonies in Africa as sources of raw materials and as openings for colonization, but as soon as one gets away from the few mineral areas, African land affords little opportunity of exploitation and will indeed only continue to exist productively if its overlords adopt and persist in a self-denying policy

SEVERE SOIL DRIFTING NEAR CADILLAC IN SOUTHWESTERN SASKATCHEWAN.

The sand has drifted 3 to 5 feet deep around the buildings, and the farm has been abandoned. (Photograph by Dr. E. S. Hopkins, Ottawa.)

1. Untouched forest. 2. A clearing for potatoes. 3. The later stage.

KIKUYU RESERVE.

(Photograph by R. Barnes, sent by Colin Maher, Department of Agriculture, Nairobi.)

THE FUTURE OF PALEONTOLOGY [1]

By Joseph A. Cushman

In these days the man of science holds an enviable position. His outlook on the world in general, so far as his scientific point of view is concerned, is not dimmed by the terrors of war, by changing political trends, nor by recessions of the business world. True, all of these may limit his productivity or actually interfere with his work. Nevertheless, he has a grasp on the laws of the universe which are unaffected by any of these changing conditions. He needs no appeal to a court, for the laws with which he deals are the eternal verities. So in the shifting sands of the human world and the ebb and flow of man-made tides he may feel sure of the ground on which his science is based, knowing that its laws will be operating when all these other temporary troubles are long forgotten.

To the astronomer who deals with the whole universe and whose time basis is one of light-years, such trivialities as the rise and fall of dynasties or the wars of races on this small planet of ours are of little consequence when he looks out upon ordered worlds each true to its own pathway through space. So, too, other sciences are based upon less broad a field, but their vastness is such that one may at least temporarily broaden his outlook from the world about him and turn back the records of time to other worlds long passed away.

To the paleontologist is given a rare privilege, for his is the stewardship of the oldest book of records that we possess, the book which contains all that we know of the progress of life upon this planet of ours. True, the book has had very hard usage and is imperfect. Many of its pages are badly torn and blotted; others have later records written across a page of earlier ones, so that it is difficult to trace the written lines. Many of its pages are entirely missing. Nevertheless, this is the only record of the past life of the world and as such is beyond price.

Given into his hands, it is the sacred duty of the paleontologist to study the pages with the utmost care, to translate the hidden meanings, to fill in to the best of his ability the blurred lines, and, wherever possible, to replace the missing pages.

[1] Address as retiring president of the Paleontological Society, 1937. Reprinted by permission from the Bulletin of the Geological Society of America, vol. 49, pp. 359–366, March 1, 1938.

In imagination at least, the paleontologist may review the wonderful pageant of the past life of this world of ours. His reviewing stand is placed on the ocean border high enough above the water so that he may have a clear view of its depths. Here pass before him all the marine creatures from the single-celled primitive animals to the starfish, the brachiopods, the bizarre forms of the trilobites, huge ammonites, and many other creeping and crawling animals. Then come strangely shaped fishes in the armor of medieval knights and other swimming forms so unlike any living today that they must be seen to be believed. Then, creeping out onto the land, which, while he has been fascinated by the marvels of the sea, has become covered by vegetation, come strange creations. They are leaving the teeming sea and venturing out to a new life upon the land. Soon he sees them developing varied forms, upon the surface and in the air as the first insects fly about the strange trees and plants of this primitive world. Later the reptiles develop and dominate land, sea, and air, with the huge winged Pterodactyls perhaps resembling flights of modern airplanes. The birds and mammals follow and, in turn, dominate air and land. Gradually, modern vegetation appears, and the world looks very much as it does today. The stage is set for the appearance of primitive man. As the animals and plants show their evolution, the paleontologist studying the early races of men becomes an anthropologist, and digging into his buried cities changes to an archeologist, and so to the historian.

With all this pageantry of the past, the field for the present-day paleontologist, what of the future of the science?

It may well follow three distinct but related fields: First, that of the paleontologist in his own realm; second, the relationships to the other sciences, particularly geology, where it may contribute much; and, third, as a practical aid to the development of man's economic life. Some suggestions at least will be given for all three of these fields.

The base on which to build our knowledge of the animals and plants of the past must rest upon the remains that are left to us in the deposits of past ages. To make these available for the studies of others, the fossils must be collected, described, and illustrated. This is the chore work that must be done in detail, and eventually must cover the entire surface of the globe and the vertical section of the sedimentary rocks of all ages. In the last century and a half, great progress has been made along these lines, but immense areas of the earth are yet to be explored. These will fill in many details of the picture which are now lacking. In the future we may expect explorations and development will render accessible to paleontologists rich collections from the unknown parts of Asia, Africa, the Americas, and Australia. These will not only add immensely to the known

fossil faunas and floras of past ages, but will make possible a much greater clarity of vision in making the past live again.

For all the great progress in the past, the paleontologist of the future should be especially trained and educated. Perhaps too often in the past paleontology has been merely a side issue, particularly as it is used by a geologist who has looked for fossils to give him a clue to the age of the formations with which he was working. The fossils meant simply marks or forms in the rocks, to which he attached names for future reference in correlation.

As an ideal, the paleontologist of the future should be trained as a zoologist or botanist or both, so that he may be familiar with the animals and plants of the present day. With this background he will be ready to understand the relationship, structure, and development of the animals and plants whose remains he finds in the rocks. They will represent definite characters which will allow him to classify and deal with them in their true zoological or botanical relationships. With such a training, the future paleontologist will have full knowledge of types of plants or animals with which he works and can visualize the living forms from the fossil remains that he has before him.

With greater ease of travel, and larger collections from all parts of the earth, the specialist in any group will be able to consider it as a whole, trace its evolution throughout geologic time, and chart its migrations. Although faunal study of small areas will necessarily precede, we may look forward to the time when a comprehensive study of a group from all parts of the world will be possible and a much fuller understanding of its developments and relationships will be achieved than can be attained at present. As wider collections are made, many of the gaps that now exist will be filled in and the missing links in much of the evolutionary history of plants and animals will be discovered to make a complete whole.

Although the biologist dealing with life processes gives us much information on the actual working of evolution, it is the paleontologist who must, by a study of the records of the past, bring to light the pathways that evolution has taken up to the present. For the best realization of these, the paleontologist will collect not only the adult stages characteristic of the species but all the developmental stages possible as well, to give a complete series.

Material for the study of the more detailed problems of evolution may be found in many surface outcrops, but complete sections, several hundreds of feet in length or even much longer, may be obtained by the use of cores. Those who have worked with the microfossils of such cores must have been aware of the changes that take place in a single species during the deposition represented by the core or that part of it in which the species occurs. The relationships of species and their derivation, one from another, by the incoming of new charac-

ters, may be very well seen in the close study of such cores. This line of attack on the problems of evolution will be more and more available to the paleontologist of the future. Core drilling for economic problems is rapidly increasing, and several depositories already are available for the preservation of selected cores. If additional cores for which there is no storage room could be sampled and washed so as to be stored in a smaller space, the microfossils at least would be available for future workers after exhaustion of the petroleum or other resources made core drilling no longer of economic interest in that particular region. It is to be hoped that many of the samples now in laboratories connected with petroleum companies may be preserved elsewhere when they are no longer of value to the company. Thus, the future worker may have available a treasure house of material which to duplicate would be an expensive undertaking.

Similar cores of short length have recently been taken both in the Atlantic and in the Pacific Oceans by quite different methods and for purely scientific purposes. Through the study of their microfossils, much has already been learned of changes in conditions during Pleistocene times. Also, it will be possible by a continuation of such methods to learn much of the sediments and even of outcropping formations now deep in the oceans. In time, when methods shall have been developed for taking much longer cores, it will be possible to study the fossil content of areas otherwise entirely unavailable. The possibility of core study has much ahead for the future paleontologist.

As material from cores should be preserved whenever possible, so outcrops, particularly of type localities from which many species have been described, might also be a matter of consideration for preservation. A few localities, especially noteworthy for their vertebrate fossils, have been made into State parks or national monuments. It is possible that other localities or outcrops should be preserved in like manner. The famous Eocene locality at Grignon in France is now preserved and the fossils taken carefully, so that full use is made of them. Certain localities near State or other universities might be preserved in this way with little cost and be made a source of great scientific value to future paleontologists.

A beginning has been made in a few museums to show to the public, groups representing fossil animals and plants in their probable relationships when living. It would seem an excellent opportunity for making an educational contribution to the general public if more museums would take up this work. With modern methods of group presentation as shown in many museums, it should be possible to make groups to show some of the characteristic animals and plants of geologic periods in a series that would be of real interest, and make more alive the facts of paleontology and evolution. This should be a great field of opportunity for paleontologists of the future to recon-

struct the life of earlier ages, so that it may become real to many interested, but nonscientific, persons to whom otherwise the fossil record would be an unopened book.

Paleœcology is a fairly new word, but it stands for what should be an excellent field for the well-trained paleontologist of the future. The study of the environment in which the fossil animals and plants lived and their relationships to one another and to their surroundings is a fascinating one. The student of paleœcology must have a broad knowledge of the ecology of living plants and animals before he can begin to grasp the relationships of those of the past. It will be a test of the imagination, under control of what is already known, to make these fossil animals and plants live again in their own environment, to explain their structural adaptations and their interrelationships with one another. This will give to the future worker data for the explanation of the rapid extinction of species, and even whole faunas, and the appearance of others to take their places. The many unusual forms, so unlike those of today, may be found to be equally well fitted to special conditions very unlike our own.

The study of environmental conditions will probably help to explain the great migrations of animals that have taken place in past geologic ages whose paths are only obscure as yet. The future collections of Africa and Asia will undoubtedly give us detailed information of the path of migration of those elements of the Miocene and Recent faunas of Australia that are so closely allied to those of the Eocene of the Paris Basin and to the Oligocene of the Gulf Coastal region of the United States, to cite a single example.

From a study of these migrations and distributions, decided aid should be given toward the study of paleogeography. Knowledge of the distribution of animals and plants is of great value in determining the distribution of land and water areas in past ages. When the ecologic factors are better known, it will be possible to give more definitely the depth of water and relative direction of shore lines from any particular area, and the distribution of fossil pelagic foraminifera may give a clue to the extent and direction of ocean currents of the past.

In the field where paleontology has been most useful, that of an aid to the stratigraphic geologist, the future will add much in detail to what is already known. More cooperative work will be done to give illustrated works of entire faunas of key beds so that all the elements of the fauna will appear in a single volume or a series of volumes instead of having the information scattered as it is today. Such a series would be of inestimable value to the geologist as well as the paleontologist, and it is not too early to plan for the cooperative effort to produce such works. It will take the earnest and combined efforts of many workers to make possible such standard works, but

it will help greatly to lessen the confusion that arises when formations are encountered, and the scattered or unavailable literature is not at hand for aid in placing them in proper position in the section.

Efforts should be gradually made to correlate more closely the faunas occurring under different ecologic conditions but of contemporaneous age. The faunas of shallow littoral waters are usually very different from those of even moderately deeper water. Where beds cannot be traced over long distances, and changes in sediments occur, due to differences in depth, correlation is difficult. The student of paleœcology should find studies along this line fascinating to himself and the results very useful to the geologist and stratigrapher. It is very probable that some of the present-day controversies over the relative ages of different beds might be easily and definitely settled if such ecologic factors were better known. There are examples in our sections where fossils of one group of animals seem to indicate a different relationship than those shown by other animal groups. A closer cooperation of workers on different zoologic divisions will probably show that one group was more rapidly changing under the particular environmental conditions, and that, under certain conditions, greater weight should be given to one group than to another. Very much is to be learned by the paleontologist of the future along these and related lines.

In the realm of economic geology, paleontology, especially micropaleontology, has demonstrated great usefulness. Particularly in petroleum discovery and recovery, the microfossils have been of inestimable value. Their usefulness has been due to their immense numbers, especially the foraminifera, and the fact that their small size allows them to be recovered unharmed by the process of drilling. The rapid changes in characters in the foraminifera and the large number of species usually present in a relatively small sample make them especially valuable for correlation purposes. The use of microfossils for correlation is already widespread in the search for oil. Shallow core drilling to determine subsurface structures is now used to a great extent. Where no surface outcrops allow the field geologist a clue to what is beneath, this method opens up a relatively inexpensive method of revealing subsurface structures.

The value of such work depends upon the extent to which the microfaunas of the beds of the section are known. Particularly where subsurface faulting must be accurately located as in some of the areas of Texas, the point of change of faunas must be recognized within very narrow limits. Keen discrimination and an intimate knowledge of the various faunas are necessary for success in this rapidly growing field. A large part of this information, and the material upon which it is based, is not generally available, but is kept in the files of different companies who are operating in these fields. Such information should

be preserved, so that the scientific results will not be lost, and have to be later obtained with much effort. Cooperation between the scientific staffs of various oil companies is much more in evidence than it was even a few years ago. If this scattered information could be gathered together and gradually published, with the necessary illustrations, it would be of immense help to all those seeking data along this same line. If some organization connected with petroleum work could sponsor such a program of cooperative studies, the results would be of immense practical value.

Much of the future work and the rapidity of progress in paleontology, as in all other lines of human endeavor, depends greatly upon organization and cooperation. In this way, waste of effort through unnecessary duplication will be avoided. The individual worker in his chosen field will feel the stimulation that results from his knowing that what he does is part of a whole which he himself can see in its entirety.

Under capable leadership, it will be possible to correlate various groups of workers so that the fossils of the various parts of the geologic time scale will be illustrated, described, and their distributions, ecology, and relationships known in a series of well-thought-out volumes, which, although they will be added to as progress continues, should be, nevertheless, sufficiently exhaustive so as to be standard works for a long while to come.

An added service that has been attempted on a small scale is the distribution of collections of fossils either as duplicates or in the way of casts. This work has been done to some degree by the United States National Museum, so that casts or duplicates are available for many of the elements of Old-World faunas for comparison with our own. From type localities, as already mentioned, collections could be made which would be of great value in exchanging with other institutions. Individuals, especially those working with microfossils, can send paratypes of their species to widely scattered museums, or to other workers, who could reciprocate and make a first-hand knowledge of their material possible.

With many of the older species, poorly illustrated and inadequately described as they often were, an attempt should be made to refigure and redescribe the species from the actual type specimens where they are still extant. Much confusion would be eliminated by this relatively simple undertaking.

It is to be hoped that many similar plans to carry on the future work of paleontology will suggest themselves to the workers in this science. Progress will continue to be made, but it will be more rapid and more sure if greater cooperation among paleontologists can

114728—39——22

be assured and if better methods can be found for publishing their works and of making these works more available.

To these young men and women who are hesitating in the choice of a future career, that of the research worker is here recommended for consideration. It means a lifetime of devotion to a cause which probably will bring neither fame nor fortune. One who chooses it must find most of its rewards within himself. He must leave the easy highways of the valley and be prepared to climb, first, the winding mountain roads that others before him have graded and made easy, then the upper mountain trails with occasional vistas that will give him a promise of what is ahead if he continues to climb. Finally, he will come out onto the bare, wind-swept, rock ledges above the timber line, marked only by rock cairns of those who have ventured before him. The broadened view may hold him for a time, but he will surely feel the urge to press on to the eternal snows of the mountain peak ahead. There, he will find no trail to guide him, and he must push on through the fresh snow, leaving behind footprints for others to follow if they will. He knows well that he will never reach the summit, but the urge to go forward is all-compelling. When he has gone on to the limit of his strength and sinks down on the snow-fields, he will feel within him, whether the world says "Well done" or not, that he has been true to the inner urge of his own soul and his reward is in the knowledge that he has carried the standard of science a little further into the unknown.

THE METEOROLOGY OF GREAT FLOODS IN THE EASTERN UNITED STATES [1]

By Charles F. Brooks and Alfred H. Thiessen

During January 1937 a standing high-pressure area in the southwestern North Atlantic sent steamy tropical air into the United States day after day, which, on meeting a persistent flow of polar air in a nearly stationary southwest-northeast belt, precipitated phenomenal rainfalls. Locally exceeding 20 inches, the rains extended across the lower Mississippi and almost simultaneously over the entire Ohio Basin. Dammed by the flooded lower Mississippi, the Ohio River became a lake, 15 miles wide in some places, and nearly 10 feet above the highest stages previously known. All the river cities, except Cairo, were partially submerged; one-sixth of Cincinnati was under water, one-half of Evansville, and more of Louisville. The inundation of Louisville drowned several persons and caused an estimated monetary loss of $200,000,000: that the loss of life was not very much greater was owing to the extraordinary service of the local radio station WHAS. In 5 days this station broadcast 16,500 separate appeals for help. The calls were heard on sound trucks at the shore and on radio-equipped boats that were thus able to effect the removal of at least 58,000 persons from their flooded homes.[2] The January rainfall at Louisville was 18.8 inches, of which 10.31 fell in the 5-day period January 20–24. The death toll for the whole flood was 137, as compiled by the American Red Cross.[3] The number injured was 544; but 16,445 individuals had to be hospitalized. Over the 12,721 square miles affected, 1,495,287 people were directly subjected to the flood, and 1,062,661 of these were completely dependent on the Red Cross for every primary necessity of life; 155,134 families required rescue from the flood, transportation to dry ground, and immediate food and shelter; they were taken care of in 1,575 refugee centers and tent cities; 73,817 other families required food and clothing. Financial assistance in rehabilitation was later required

[1] Reprinted by permission, with additions and revisions, from The Geographical Review, vol. 27, No. 2, April 1937, with some substitutions and addenda by the authors. The assistance of officials of the U. S. Weather Bureau and the American Red Cross in supplying helpful information is gratefully acknowledged.

[2] Bauman, Wm., Narrative of a flood refugee; Carleton, H. B., A boatman's story, Dixiana, vol. 1, pp. 3–17, 1937; and Breaux, G. A., in Filson Club Hist. Quart., April 1937.

[3] The Ohio-Mississippi Valley flood disaster of 1937, report of relief operations of the American Red Cross. ARC 977, 252 pp., illus., bibliog., Washington, D. C., 1938.

by 97,247 of these families. Private contributions of cash and supplies to the American Red Cross totalled $28,000,000; while the Federal Government spent $13,000,000 and loaned $7,000,000. A conservative estimate of the flood cost is $417,000,000, not including the value of some 300,000,000 tons of top soil that the Soil Conservation Service estimates was carried away from the Ohio watershed. The flood of 1937 must be considered the greatest American flood on record.[4]

This unprecedented flood on the Ohio and lower Mississippi Rivers, coming so soon after the extraordinary floods of March-April 1936 in the middle and north Atlantic States, compels an examination of the relation of floods to weather in an effort to solve or mitigate their menace. What are the meteorological features of previous great floods, such as those of 1913, 1922, and 1927 in the Mississippi Basin; of still earlier general floods, such as those of 1882, 1889, 1903; of the less widespread but remarkable overflows that followed excessive rains in July 1935, November 1927, July 1916, and June 1915? What flood-control measures do meteorological considerations most favor? And are flooding rains predictable?

---

[4] Swenson, Bennett, The Ohio and Mississippi River floods of January-February 1937, Monthly Weather Rev., Suppl. 37, 55 pp., 30 figs., 1938. See also, Devereaux, W. C., The Ohio River flood of 1937, Bull. Amer. Meteorol. Soc., vol. 19, pp. 330-333, 1938. The flood, chiefly from the standpoint of water supply and sanitation, is extensively discussed in the Journ. Amer. Water Works Assoc., pp. 1230-1307, Sept. 1937.

TABLE I—*Meteorology of certain great floods* [1]

Date	Points worst affected	River heights above flood stage (feet)				Area submerged (square miles)	Destruction		Maximum rainfall (inches)				Region of heaviest rainfall	Rainy month departures				Previous condition of ground
		Worst place	Cincinnati (52 feet)	Cairo (40 feet)	Vicksburg (43 feet)		Deaths	Damage in $1,000,000	1 month	10 days	5 days	1 day		Pressure at Bermuda (inches)	Temperature °F. Nashville	Omaha	San Diego	
January 1882	Nashville, Tenn.	13.2	6.6	11.9	----	-------	0?	0.4+	18.1	----	----	5.1	Eastern Texas to West Virginia.	+0.09	+3.8	+6.8	−3.9	Wet.
May-June 1889	Johnstown, Pa.	20c	----	----	----	-------	9,000c	39	12.5	9.8	9.8	8.4	Western and central Pennsylvania.	−.02	−2.6	+.1	+.2	Dry.
May 1903	Kansas City, Mo.	14	1.2	10.6	6.8	6,820	100	40+	18.5	9.7	6.3	3.7	Oklahoma to southern Minnesota.	−.04	+.6	+.5	−.1	Wet.
March 1913	Dayton, Ohio	10.1	17.9	14.7	7.3	-------	732	113	13.1	11.8	11.2	7.0	South central Indiana and central Ohio.	+.30	−1.2	−2.1	−1.4	Wet.
June-July 1915	Kansas City, Mo.	7	----	----	----	-------	0	10.5+	14.9	8.2	7.0	5.8	Lower Missouri Basin	−.06	−1.9	−4.0	+1.0	Wet.
July 1916	Western North Carolina	22.5	----	----	----	-------	20	22	37.4	31.1	21.4	22.2	Appalachians and southeast.	+.01	−.7	+6.2	−2.2	Wet.
March-May 1922	St. Louis Indianapolis	4 10c	} .2	13.6	12.0	13,200	0	17	17.6	11.5	11.3	9.3	Lower Mississippi Basin	+.14	+1.3	+3.5	−1.9	Wet.
December 1926-January 1927.	Nashville, Tenn.	14.8	7.1	8.9	1.5	-------	3	3	19.4	14.8	13.1	6.3	Eastern Texas to West Virginia.	+.01	−.1	−1.3	−.8	Wet.
April-May 1927	Southeastern Arkansas and south central Louisiana.	13.7	7.1	16.4	13.7	6,880	219	284	23.8	18.6	18.5	18.5	Arkansas	+.06	+3.4	+1.1	−.2	Wet.
November 1927	Winooski Valley, Vermont.	10c	----	----	----	-------	88	40	14.5	9.9	9.7	9.4	New England	+.14	+4.4	+.1	+3.6	Wet.
July 1935	Southern half of western New York.	7.5	----	----	----	-------	52	26	19.4	14.6	11.7	9.0	Western and central New York.	+.17	+1.0	+7.0	+.6	Dry.
March-April 1936	Western Pennsylvania and southern New England.	21	8.6	12.8	----	-------	470	300	10.0 23.9	8.0 20.2	7.4 12.3	4.5 6.5	Central Appalachians and New England.	+.15	+4.6	+5.4	+.7	Wet.
January-February 1937	Louisville, Ky.	29.1	28.0	19.5	10.2	-------	137	417	23.1	17.1	11.2	4.4	Arkansas to southern Ohio.	+.36	+3.6	−12.0	−4.0	Wet.

[1] Compiled from Monthly Weather Review, Monthly Weather Review Supplements 22 and 29, World Weather Records, and miscellaneous sources.

CAUSES OF THE GREAT FLOODS

Two elements are always involved in the production of a great flood in the eastern United States: a rapid and continuing flow of moist tropical air into the country and a frequent or persistent elevation of this tropical current by a colder air mass over the same region.

Such a wind situation depends on a persistent high-pressure area in the western Atlantic and another high over the central or northern interior of the United States or farther west. The Atlantic high pushes air from the tropical Atlantic northwestward, northward, or northeastward, while the western high pushes the polar air southeastward, southward, or southwestward. The low pressure trough between the highs is marked by one or more moving centers. Its position varies in accordance with the relative strengths and locations of the two highs from day to day. The western high or an offshoot from it often moves eastward; thence it may pass out to sea, to strengthen the Atlantic high and, consequently, the landward flow of tropical air. This is what happened January 20 to 24, 1937. Along the front between the polar and the tropical air masses continuous, sometimes violent, ascent of the warmer current is in progress. Either the tropical air is the aggressor (warm front) or the polar air is making gains (cold front). In either event, the tropical air is forced upward, though usually with less violence on the warm front than on the cold. This is why it rains.

When moist tropical air is forced to rise, it expands in the lower pressure aloft and cools at such a rate that in an ascent of 2 miles three-quarters of its vapor will be precipitated. If such air, originally nearly saturated at 77° F. (25° C.) over the Caribbean Sea, has been chilled over land in middle latitudes to 68° F. (20° C.), a layer of such air 2 miles (3.2 km) thick would contain about 80,000 tons of water vapor over each square mile of surface. If it were forced upward over a cold air mass or by convergence to a height of 2 miles, some 60,000 tons of its vapor would be precipitated, or the equivalent of 0.8 inch (2 cm) of rain. Since the slope of the upper surface of the cold air mass is commonly only 1 or 2 percent, the lifting of the tropical air mass by 2 miles would require the passage of 100 or 200 miles of wind, which at a velocity of only 4 to 8 miles an hour would complete the entire elevation in 1 day. Since the advance of a tropical air mass commonly proceeds at 30 to 40 miles an hour, it is easy to see how rains of several inches in 1 day may fall when a tropical air mass mounts a polar one. The heaviest fall occurs when the polar front is standing or advancing under the tropical air mass.

The weather preceding any flood is important in its conditioning of the watershed as regards run-off. If the weather has been rainy before the heavy continuous rains that make the flood and the ground has become soaked, run-off naturally is favored. With well-frozen ground a like condition exists.

The run-off that produces great floods of the Mississippi is between 25 and 30 percent of the rainfall over the entire drainage area, which, however, includes semiarid lands.[5] In Tennessee the average run-off is estimated as 45 percent.[6]

The current weather conditions tending to make floods are continuously heavy rains and temperatures above freezing. Freezing during the night is a flood deterrent. Warm rains and high temperatures with strong winds melt the layer of snow if there is any; and rain and snow water run off together. An old snow cover is so dense, however, that much more time is required to remove it than freshly fallen snow, the more so if it lies in the shelter of a forest. Ten inches of rainfall in a day or two will produce a flood anywhere and at any time in the eastern United States. Five inches will suffice if the ground is bare or lightly snow-covered and already saturated or frozen. Under such conditions 60 to 100 percent of the water may run off into the streams. The Muskingum River (Ohio) flood-control plan is based on a hypothetical 10 inches of rain in 5 days on frozen ground with a 90 percent run-off.

On the other hand, dense vegetation and a dry soil or a deep snow cover on unfrozen ground may wholly absorb 5 or more inches of rainfall. Thus in March 1936, in experimental plots in the upper Susquehanna drainage, while 60 percent of a 5-inch rainfall over several days ran off of open cultivated fields that were frozen, none came from the unfrozen forest near by; and at the Arnot Soil Conservation Experiment Station in Schuyler County, N. Y., while a run-off of 7.9 inches, including melted snow, came from frozen, open fields after 6.4 inches of rainfall, March 10–19, 1936, only 0.1 inch came from a beech-maple forest plot, where 12 inches of snow remained unmelted after the snow had disappeared in the open.[7] Of the 27 inches of rainfall causing the great flood of the Yazoo River, Miss., in 1931–32, 62 percent ran off from cultivated fields, 54 percent from abandoned fields, 2 percent from scrub oak, and 0.5 percent from undisturbed oak forest.[8] The Soil Conservation Service reported that 8 inches or 95 percent ran off of plowed land in Ohio in the heavy rains of January 1937, but only 2 inches from comparable areas under grass and trees.[9]

---

[5] Frankenfield, H. C., and others: The spring floods of 1922, Monthly Weather Rev., Suppl. No. 22, pp. 7–8, 1922; idem; The floods of 1927 in the Mississippi Basin, ibid., Suppl. No. 29, p. 31, 1927.

[6] Forests in flood control, Supplemental Rep. to Committee on Flood Control, House of Repr., 74th Congr., 2nd Sess., on H. R. 12517, p. 4, Washington, 1936.

[7] Ibid., p. 6.

[8] Ibid., pp. 3 and 51–59.

[9] For other data on storm-rain run-off, see Hoyt, W. G., and others, Studies of relations of rainfall and run-off in the United States, U. S. Geol. Surv. Water-Supply Paper, 722, esp. tables 30, 33, 36, 39, 42, 45, 48, 51; Washington, 1936.

SEASONS OF GREAT FLOODS

It is no accident that great floods occur only in winter or spring, even though the melting of accumulated snow is usually a minor or negligible factor. Summer and autumn rains in the eastern United States may be as great as those of winter and spring and are usually more intense, that is, the rate of fall is more rapid. There is so much more vapor in the air that strong general storms are not required for the production of excessive rains, and when a hurricane puts the vapor through the cyclonic wringer at high speed the rains exceed any that can be produced in winter. Fortunately, however, there is in the active vegetation of the warm season an effective intercepter of rain, a mechanical hindrance to run-off, and a rapid user of ground water. Hardwoods in Wisconsin when in leaf intercepted 25 percent of the rainfall but when dormant only 16 percent;[10] but this difference of 9 percent of the rainfall is but a small part of the total change in run-off from summer to winter for the same rainfalls. Besides the several effects of vegetation, evaporation from the ground is greater in summer. A comparison of run-off with rainfall at Knoxville, Tenn.,[11] shows an average run-off for 1900–23 of only 28 percent in summer and 30 percent in autumn, whereas in the 3 months January to March it was 64 percent. Even in summer months with 7 to 12.5 inches of rainfall the run-off was only 25 to 37 percent. The run-off of 4.06 inches from the 10.89 inches of rainfall in the hurricane flood of July 1916, and that of 4.38 inches from the 12.52 inches of rainfall in August 1901, did not equal the 4.22 and 4.54-inch run-offs from the 7.00 and 7.10-inch rainfalls of the March floods of 1922 and 1913. To produce important floods in summer, monthly rains well in excess of 10 inches are required, whereas half as much will suffice in winter. Summer rains, in general, are spottier than winter ones, and excessive downpours are more restricted in area than ordinary heavy rains; so summer floods are usually more local and of shorter duration than winter ones. In the cold season the low evaporation permits the ground to stay wet for a long time after a rain, and a freezing of the ground may stop percolation. Before the rivers have carried away the water from one general rainstorm another may occur and add to the burden.

THE OHIO-MISSISSIPPI FLOOD OF JANUARY–FEBRUARY 1937

These general observations may now be examined in the specific terms of the Ohio-Mississippi flood of January–February 1937. In the eastern United States northwesterly or northerly winds normally prevail in winter, pushed from the high pressure formed by air accumu-

[10] Ibid., p. 4. Cf. also Baldwin, H. I., and Brooks, C. F., Forests and floods in New Hampshire, New England Regional Planning Commission, Publ. No. 47, pp. 5–9, Boston, 1936.

[11] Voorhees, J. F., A preliminary study of effective rainfall, Monthly Weather Rev., vol. 53, pp. 63–65, 1925.

lated over the cold continent toward the low pressure over the warm waters of the Gulf Stream and beyond. Occasionally, however, the semipermanent high-pressure area of the subtropical Atlantic, which is usually some distance east of North America, expands and builds up westward into the Bermuda region. This happened in December 1936, starting, after a cold November, a most remarkably mild and wet winter for the eastern part of the country. Bermuda pressures were only moderately high in the first 3 weeks of December, but from the 22d of that month until the 29th of January the morning pressures did not fall below 30.20 inches. The mean for January was 30.32 inches, in place of the 29.96-inch normal. Pressures must have been higher farther east, for the wind at Bermuda was prevailingly southeast to south.

Why the high formed and stayed in the southwestern North Atlantic is unknown.

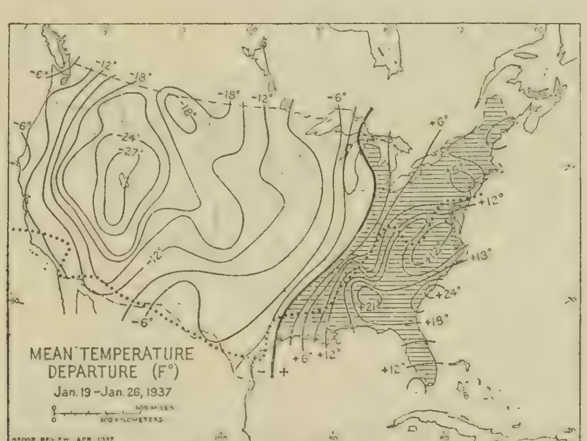


FIGURE 1.—The departure of mean temperatures from the normal for the week ending 7:30 a. m., January 26, 1937. (From Weekly Weather and Crop Bull., January 26, 1937.) The shaded area shows excess temperature (F.°); the unshaded area, deficiency; the dotted line, the southern limit of freezing weather.

To favor high pressure at Bermuda, one should expect sea temperatures to have been lower than usual there and higher than is common farther east,[12] though it would hardly seem possible that even the greatest sea temperature departures could account for the pressure anomaly. The actual values of sea temperature, however, showed departures similar to those of the air temperature, and, therefore, were adverse rather than favorable to the westward extension and intensification of the Azores-Bermuda high. The mean sea-surface temperatures for December, January, and February about Bermuda were 0.5, 3.4 and 0.5° F. above the average of the 20 years, 1912 to

[12] Cf. Humphreys, W. J.: Why some winters are warm and others cold in the Eastern United States, Monthly Weather Review, vol. 42, pp. 672–675, 1914. For a case the reverse of 1937 conditions see Brooks, C. F., The "old-fashioned" winter of 1917–18, Geogr. Review, vol. 5, pp. 405–414, 1918.

1931, as compiled by the United States Weather Bureau. The sea temperatures in the general longitude of the Azores and latitude of Bermuda, on the other hand, were 1.7, 1.0 and 2.6° F. below the normals for those 3 months.

In accordance with the pressure gradients on the south and west of this standing Bermuda high, great tropical air masses moved day after day over the hot waters of low latitudes westward and northwestward toward the United States. Passing the length of the Caribbean Sea, they turned northward into the Gulf of Mexico and entered the continent nearly saturated with water vapor to a height of 2 kilometers or more. Flooding rains were inevitable. The question was, where? The Arctic held the answer.

The major interzonal exchanges of air take place in alternating bands of considerable width. In January 1937, there was a northward

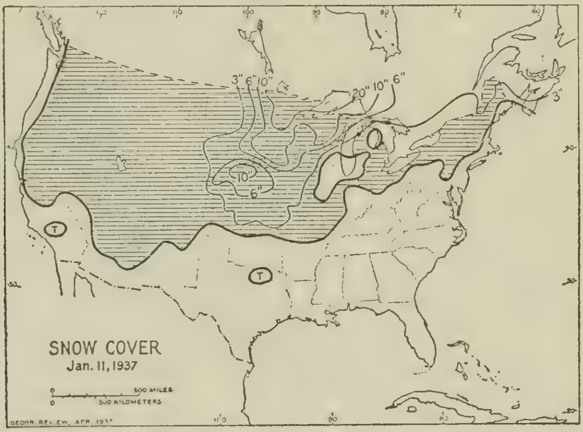
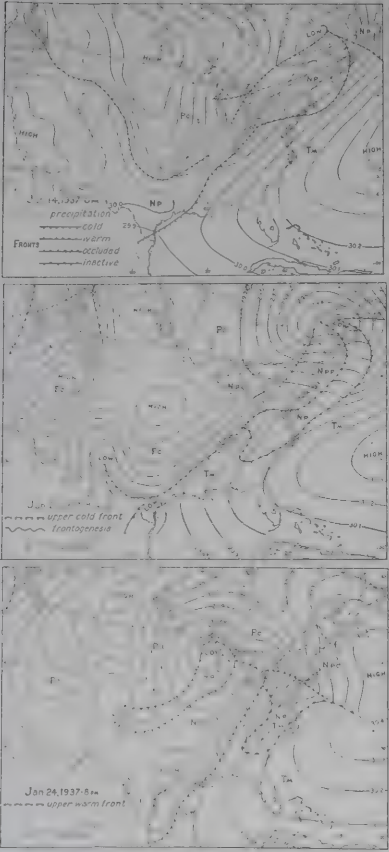
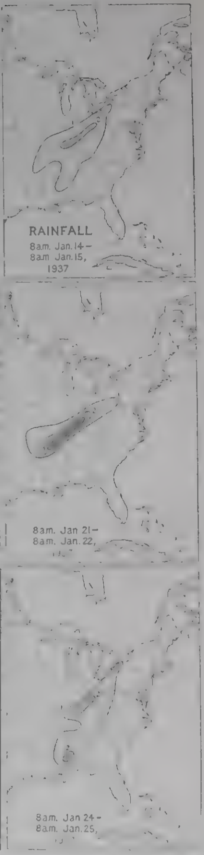


FIGURE 2.—The depth of snow on the ground, 8 p. m., January 11, 1937. (From Weekly Weather and Crop Bull., January 12, 1937.)

current of tropical air occupying a band about 2,000 miles wide from somewhere east of Bermuda to a short distance west of the Mississippi River. Its western boundary is strikingly suggested by the sharp gradient between the large positive temperature departures east of the Mississippi and the large negative ones to the west (fig. 1). From the plains to the Pacific coast and beyond a southward current of polar air prevailed occupying a band also about 2,000 miles wide.

The chilling and shrinkage of air continuously in progress in the polar regions in winter leads to an accumulation of air that must discharge toward the lightened pressures of middle latitudes. The loci of chief upbuilding of polar air masses vary somewhat from year to year, apparently in relation both to the distribution of cold surfaces, namely ice-covered sea and snow-covered land, and to the proximity of warm surfaces, for the expanded air over warm surfaces readily overflows and feeds the accumulating cold air masses.





[illegible] January 14, January 21, and January 24, 1937, respectively. (Courtesy U. S. Weather Bureau.)

[illegible]—Rainfall in excess of 1 inch in the 24 hours ending at 8 a. m., 75th Meridian Time, on January 15, January 22, and January 25, 1937, respectively.

Furthermore, the channels through which the discharges take place tend to be maintained for weeks or months. This seems partly to be owing to the locations of the accumulation areas but is also the result of conditions favoring the transport of cold air without too much warming en route. The first outbreaks of polar air lay down a carpet of snow, which thereafter neither becomes warm itself nor permits much heat from the ground to reach the top of the snow blanket; portions of the polar air masses continuing over the snow are less warmed than if they passed over bare ground; pressure over the snow-covered regions continues high; and further progress of the cold mass is facilitated.

The Arctic outpourings in the winter of 1936–37 established a favoring lane southward through the western half of North America and, with few interruptions, dominated this region, continuing drought on the Great Plains, elevating Pacific air to lay down deep snows in the far West, and freezing the oranges of southern California.

A heavy snow cover became established in the upper Mississippi Valley and upper Lakes region, where the eastern margin of the polar air mass frequently elevated the much-chilled western margin of the tropical air mass. This snow-covered region, like that over the western plateau, became a secondary booster of polar air masses, strengthening them for combat along the tropical front to the southeast (fig. 2).

The weather maps for January 14, 21, and 24, when the heaviest rains were in progress, show the principal fronts and trough of low pressure between the Bermuda and northern highs (figs. 3–5). The weather map of January 14 (fig. 3) indicates in typical form the Atlantic high and another high over the eastern slope of the Rockies. A cold front extends in a general northeast-southwest direction and lies just west of the Appalachians. It moved slowly from the morning of the 14th to the evening of the 15th. West of the frontal line was polar Pacific air, and east was tropical air. Heavy rains fell in a narrow belt extending from Lake Erie in a southwesterly direction to Arkansas.

The succession of formations from January 14 to 25 presents most interesting examples of frontal interactions, as indicated in some measure by the successive daily positions of the tropical front, shown in figure 10. Table 2 shows the daily rainfalls at selected stations, as published on the Washington weather maps.

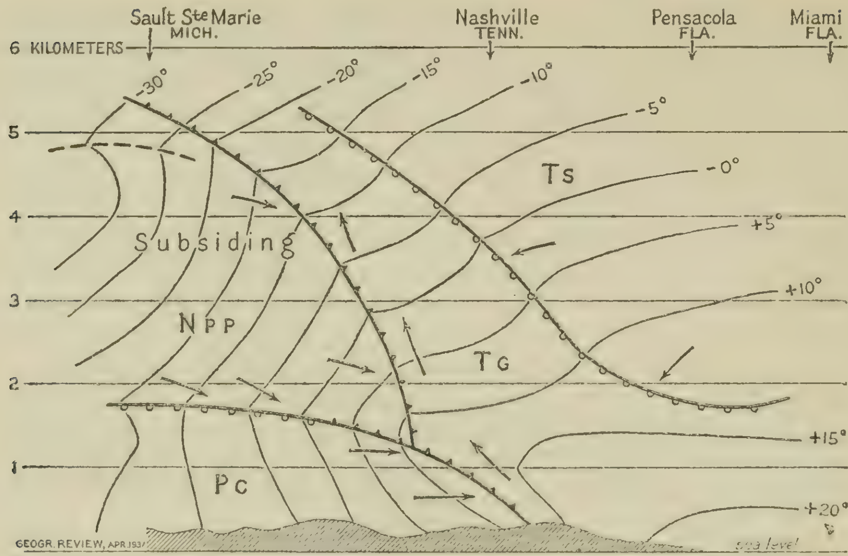


Figure 9.—Cross-section of air masses and fronts, north to south, at 8 a. m., January 22, 1937. (Courtesy Massachusetts Institute of Technology.) Warm and cold fronts shown by conventional symbols; Npp, modified polar Pacific air; Pc, polar continental air; Tg, tropical Gulf air; Ts, tropical superior air.

Table 2.—*Wind Directions and Daily Rainfalls in the Ohio and Lower Mississippi Valleys, January 1937*

[In inches, during 24 hours ending at 8 a. m., 75th Meridian Time]

Day	Little Rock, Ark.	Meridian, Miss.	Memphis, Tenn.	Nashville, Tenn.	Cairo, Ill.	Evansville, Ind.	Louisville, Ky.	Cincinnati, Ohio
14	S 0.04	S 0.01	S 0.00	S 0.01	S 0.50	SW 0.70	S 0.28	SW 0.58
15	N 1.00	W 1.50	NW 0.86	NW 1.02	NW 1.46	NW 2.52	W 2.52	NW 2.08
16	E 0.00	NE 0.00	E 0.00	NE 0.00	N 0.00	NE 0.00	E 0.00	NW 0.00
17	S 0.14	S 0.10	E 0.30	SE 0.54	S 0.14	S 0.12	SE 0.38	S 0.02
18	NW 2.00	----------	NW 2.39	W 2.28	N 1.54	NW 1.70	NW 1.54	SW 1.78
19	E 0.00	E 2.08	NE 0.00	NE 0.28	NE 0.00	NE 0.00	NE 0.00	NE 0.01
20	S 0.14	S 2.24	S 1.56	E 2.32	SE 0.12	E 0.40	SE 0.14	SE 0.04
21	E 4.36	S 0.02	E 1.52	NE 0.48	N 2.92	N 2.78	E 2.48	W 1.98
22	N 2.32	S 0.00	N 3.24	NE 0.72	N 2.06	N 1.52	N 3.34	N 2.00
23	NE 1.26	NW 0.02	N 0.78	N 1.86	N 1.36	N 0.80	N 1.22	NE 0.66
24	N 0.01	SE 1.24	E 2.08	SE 0.18	E 0.52	NE 0.46	NE 0.44	NE 0.16
25	N 0.84	N 2.32	N 0.96	NW 0.46	SW 0.90	W 1.36	NW 2.66	W 2.38
14–25	N 12.11	S. > 9.53	E 13.69	NE 10.15	N 11.52	N 12.36	Var 15.00	NE 11.69

Although heavy rains occurred early in the month, it was not until the 14th that excessive precipitation fell over the Ohio basin. This precipitation came in advance of a slowly moving cold front, which by the 15th had pushed eastward to the crest of the Appalachians and so completed a considerable lifting of a large body of moist tropical air. A day of fair weather with northwest to north winds ensued (see table 2); but by the 17th the tropical wind had again established itself over the region. Another cold front soon lifted this tropical wind and squeezed it against the Appalachians again, producing heavy rain on the 17th and 18th, followed by northwest winds and

fair weather for a day. Owing apparently to the major thrust of polar air into low latitudes along the eastern seaboard of the United States, a large return of tropical air on the 20th brought renewed heavy precipitation, which continued in the form of instability showers, even thunderstorm rains, until the 24th. (Figure 9 is a north-south cross-section of the air masses, Jan. 22.) The rainfall in this 5-day period was of the order of 10 inches in a narrow central belt from Louisville to Little Rock. The day of greatest rainfall in the Ohio Valley was the 21st (see fig. 7). The winds at the surface were mostly northerly during these heavy rains; the tropical front was to the south. The temperatures of this remarkable week are shown in figure 1. The rainfall for January 1–25, half to two-thirds of which fell in the 5

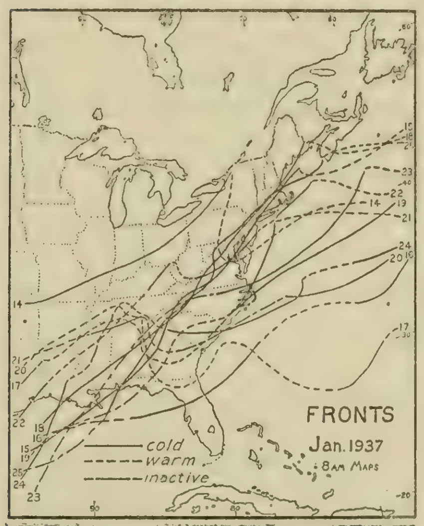


FIGURE 10.—Successive daily positions (8 a. m.) of the front between tropical and polar air masses from January 14 to 25, 1937. (From U. S. Weather Bureau Ms. Maps.)

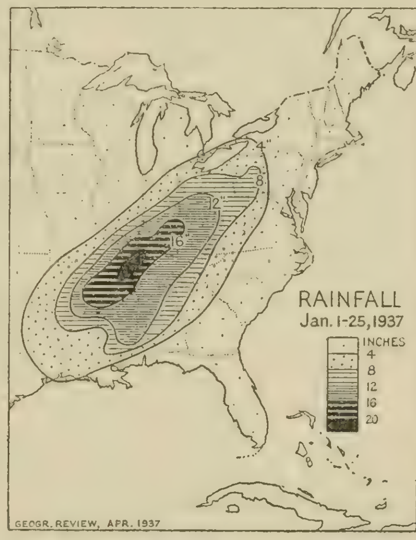


FIGURE 11.—Rainfall in the Ohio and Lower Mississippi basins between January 1 and 25, 1937. (Courtesy U. S. Weather Bureau.)

days, January 20–25, is shown in figure 11. J. B. Kincer computed that in the belt of heaviest rainfall about 100 miles wide and 550 miles long the 16 inches of rainfall amounted to more than 60 billion tons of water.[13] This precipitation was four times the normal amount.

Table 3 shows the flood stages produced throughout the length of the Ohio River, which, except at Pittsburgh, reached the highest stages ever known. One of the meteorological hazards in a great flood, when the waters are lapping the tops of the levees at the edge of a moving lake miles wide, is the wind. Not only does the wind raise erosive waves, but it also raises the stage of the water. Thus at Memphis after an apparent crest had been reached, a 25-mile wind

[13] Record-breaking January drought, floods, freezes, and early blooms, Information for the Press, U. S. Dept. of Agriculture, January 30, 1937.

raised the level by 0.1 foot. The hazard of wind action is not so great as on a lake of similar dimensions, because the flood waters are usually shallower and projecting trees and buildings serve to reduce both the wind velocity and the disturbance of the water.

When so enormous a quantity of water is involved, spread out over the lowlands, the passage of even great masses downstream lowers the upstream stages but slowly. The quantity of water represented by one foot when the flood is at its height is equal to that represented by several feet at lower stages. So great was the discharge of the Ohio relative to the Mississippi at the junction of the rivers that in this 1937 flood the flow of the Mississippi above the mouth of the Ohio was reversed. This means that all the run-off of the Mississippi above Cairo was stopped for a time and that even moderate rains plus the water from the melting of the great quantity of snow in the upper Mississippi and middle Missouri valleys might have raised the levels of these rivers above flood stages before the flood waters of the Ohio passed on. Frankenfield found the damming effect of a flooded Ohio nearly to St. Louis. Similarly the great discharge of the Arkansas and other streams into the Mississippi below Cairo created a water dam. It is obvious why the period of high waters in the lower Mississippi is protracted.

TABLE 3.—*Maximum flood stages, Ohio and lower Mississippi, January and February* [1]

Station	Flood stage	Duration above flood stage, 1937	Crest, 1937		Previous record	
			Stage	Date	Stage	Date
	Feet					
Pittsburgh	25	Jan. 18–20, 21–27	34.5	Jan. 26	46.0	Mar. 18, 1936
Portsmouth	50	Jan. 18–Feb. 3	74.2	Jan. 27	67.9	Mar. 31, 1913
Cincinnati	52	Jan. 18–Feb. 5	80.0	Jan. 26	71.1	Feb. 14, 1884
Louisville	28	Jan. 16–Feb. 7	57.15	Jan. 27	46.7	Feb. 16, 1884
Evansville	35	Jan. 10–Feb. 19	53.75	Jan. 31–Feb. 1	48.4	Apr. 5, 1913
Nashville	40	Jan. 3–10, 19–Feb. 4	53.8	Jan. 26	56.2	Jan. 1, 1927
Cairo	40	Jan. 9–Feb. 27	59.5	Feb. 3–4	56.4	Apr. 20, 1927
Memphis	34	Jan. 20–Mar. 1	[2] 50.3	Feb. 9–10	[2] 46.6	Apr. 9, 1913
Vicksburg	43	Jan. 30–Mar. 14	53.2	Feb. 21	58.6	May 4, 1927
New Orleans	17	Feb. 7–Mar. 19	19.3	Feb. 28	21.3	Apr. 25, 1922

[1] Data from U. S. Weather Bureau gage records.
[2] Beale St. gage.

WESTERN COLD THE ACCOMPANIMENT OF EASTERN FLOODS

The flood so eclipsed all else in weather news that the extreme cold in the West received little general attention. Throughout January polar air masses were just as persistently covering the West as tropical ones were deluging the East. Oranges were freezing in southern California while they were ripening too fast in Florida and early fruit trees were blossoming in southern South Carolina. Figure 1 shows temperatures more than 20° F. below normal in the central and south-

ern plateau region, where a blanket of snow maintained the original polar frigidity of the air. As thrust after thrust of polar air pushed southward in floods deep enough to overtop the usually protecting mountain wall of southern California—as indeed the floods of waters had overtopped the protecting walls along the great rivers in the East—this famous subtropical corner of the United States experienced a month of frequent freezes, ice, and occasional snow and was often colder than southern New England. The mean temperature of January at Los Angeles was 1.3° F. lower than the coldest on record. Two pronounced periods of cold, January 7–11 and 19–28, the latter coinciding with the rainiest period in the Ohio Valley, destroyed about 40 percent of the orange crop, despite frantic efforts to heat the orchards.[14] Farther north, real wintry weather prevailed over the

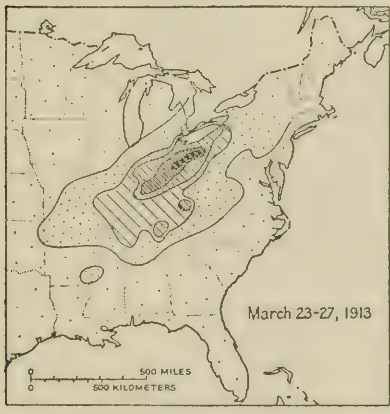


FIGURE 12.—Rainfall, Mar. 23 to 27, 1913 (after F. J. Walz, Monthly Weather Rev., March 1913; map opposite p. 368).

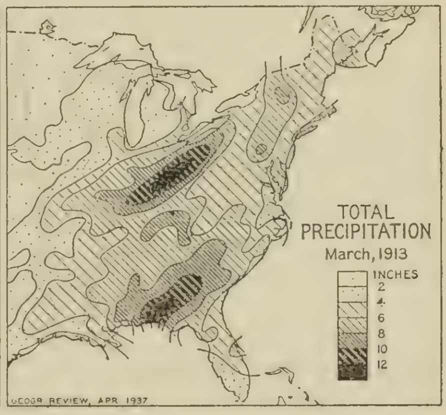


FIGURE 13.—Total precipitation in the eastern United States, March 1913.

coastal belt as well as to the east. At the end of January Portland was buried in its heaviest snowstorm of record.

Is western cold the normal accompaniment of eastern floods? In table 1 are shown temperature departures of months when flooding rains were producing great floods in the east. Subnormal temperatures in San Diego have been coincident with the chief rainy months of all other general floods of winter or early spring in the Ohio and lower Mississippi valleys since 1882: the years 1883, 1897, 1903, 1907, 1912, 1916, 1920, and 1926 (December). Obviously, widespread and great flooding rains in the Ohio and lower Mississippi valleys are attended by cold weather in southern California owing to a natural opposition between the great interlatitude currents of air.

[14] Cf. Ackerman, E. A., The 1937 California freeze. Bull. Amer. Meteor. Soc., vol. 18, pp. 240–241, 1937 Young, F. D., The 1937 freeze in California. Monthly Weather Rev., vol. 66, pp. 311–324, 13 figs., 1938

SIMILARITIES BETWEEN THE OHIO FLOODS OF 1913 AND 1937

The conditions causing the excessive rainfall of up to 14 inches in northern Tennessee and 17 inches in northeastern Arkansas in January 1913, and from 13 inches in southwestern Indiana to 12.7 in north-central Ohio in March 1913, were almost identical with those of January 1937. The pressure at Bermuda was 0.19 inch above normal in January 1913 and 0.30 above normal in March; which are to be compared with 0.36 above normal in January 1937, though during the heaviest rains the pressure departure of March 23–27, 1913, +0.39, exceeded that of January 20–25, 1937, +0.20.[15]

The rainfall, though not so great over the Ohio and lower Mississippi watersheds as in the flood of 1937, nevertheless produced excep-

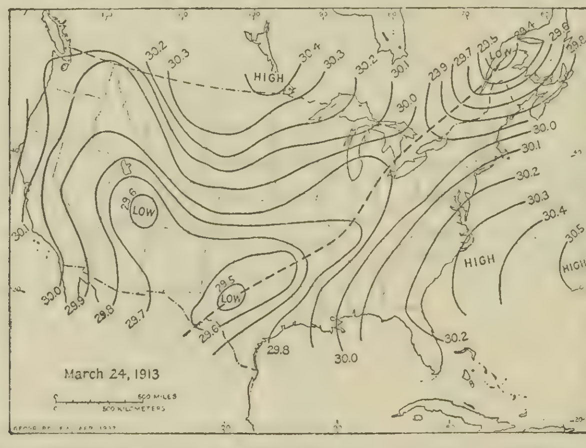


FIGURE 14.—Weather map of 8 p. m., March 24, 1913. (Courtesy U. S. Weather Bureau.)

tional floods in the Ohio basin. In January 1913 a number of low pressure troughs parallel to the Ohio in regular succession were accompanied by heavy rains south of the river in the first half of the month and north of it in the last half. A crest of 62.2 feet was reached at Cincinnati on the 15th. Before the flooding rains the ground was neither snow-covered nor frozen.[16]

The second flood, which, after rising 43.5 feet in 5 days, culminated at 69.8 feet on April 1 at Cincinnati, was due to the tremendous rains of March 23–27,[17] when more than 10 inches fell at four stations (fig. 12). The occurrence of three tornadoes in southern Indiana, southern Illinois, and Kentucky on the evenings of March 23 and 24 and the morning of the 25th was further evidence of an extraordinary intensity of convection of the tropical air. The sudden rise of the Miami, at

[15] Swenson, loc. cit., p. 36.

[16] Henry, A. J., Rivers and floods, January 1913. Monthly Weather Rev., vol. 41A, pp. 148–149, 1913.

[17] Idem: Rivers and floods, March 1913, ibid., pp. 485–492.

Dayton, 17 feet in one day, was mainly responsible for the large loss of life, totaling 732 persons.

Between the great high, 30.53 inches, at Bermuda, which was driving the tropical air, and the strong northern continental high, which was pushing the polar air kept well chilled by the deep snow cover of the region about and westward of Lake Superior, much as in 1937, the trough of low pressure moved but slowly for several days (fig. 14). The fronts of 1913 were farther north than those of 1937, and the belt of excessive rainfall in March 1913 (fig. 13) was about 100 miles to the north and somewhat to the east of that of 1937 (fig. 11);[18] and no excessive rains fell across the lower Mississippi in March 1913. The line dividing plus and minus temperature departures was farther east in 1913 (85th meridian) than in 1937.

COMPARISON WITH FLOODS OF 1922 AND 1882

In March 1922 a well-developed high in the southwestern Atlantic, averaging 0.14 inch above normal for the month at Bermuda, sent a copius flow of tropical marine air into the United States. Encounter with polar air masses took place over a broad area of the interior. Precipitation was so widespread that, with the exception of the Tennessee and Cumberland Rivers, the Mississippi and all its tributaries were in flood at the same time. The rainfall contributing to this flood as a whole, counting all the precipitation from January to April inclusive over the entire 1,250,900 square miles of the Mississippi drainage basin, averaged 10.58 inches, 33 percent of which came in March and 36 percent in April. The run-off was 25 percent. Regionally the March rainfall ranged from 13 inches in eastern Arkansas to 11 in central Kentucky and up to 15 in Louisiana and 14 in southern Mississippi. The rain fell mostly on March 10, 14 to 15, and 30 to 31, when the tropical front passed through these regions; while the supply of tropical air was maintained by the Bermuda high, which was particularly strong in these three periods. Daily rainfalls were commonly 1.5 to 3 and nearly 4 inches. April's excessive rainfall was mostly 12 inches in southeastern Kansas to 9 inches in central Indiana.[19]

In January 1882 there was a southwest-northeast band of excessive rainfall extraordinarily like that of January 1937 (fig. 11), with rainfalls of 8 to 10 inches in eastern Texas up to over 15 inches in eastern Tennessee; but this band lay about 100 miles south of that of 1937.[20] In February 1882, 8 to 10 inches of rain fell over Arkansas and more than 8 inches over the lower Ohio Basin. The Cumberland River at Nashville rose to 54 feet 7 inches, just topping the great flood of 1847. The flood was due chiefly to the excessive rains, locally 3

[18] Cf. Swenson, loc. cit., fig. 24.

[19] Frankenfield, The spring floods of 1922, loc. cit.

[20] Cf. Swenson, loc. cit., fig. 24.

inches a day on January 12 to 13, 16, 21, and 27 to 28. Bermuda pressures were 0.09 inch above normal in January and 0.08 above normal in February, and temperatures were generally above normal throughout the eastern and central United States. North of the flood belt and in the northeast there were heavy snows.

The West, as usual when the central valleys are flooded, was cold. Southern California experienced the severest freeze and heaviest snowstorms ever known. On January 13 snow fell generally, even at San Diego, and at Riverside it was deep enough (5 inches) for sleighing among the orange groves. Frost occurred on 29 days of January in southern California and on 20 days of February.

Another visitation, almost identical with that of January 1882, came in December 1926, when, after wet preliminaries, a total of nearly 10 inches of rain fell over the Cumberland Valley in 9 days and the river at Nashville reached 56.2 feet. Bermuda pressures were high during the rainy spells of the month.

APRIL AND MAY FLOODS IN THE MISSISSIPPI VALLEY

Middle and late spring floods, though caused in much the same manner as the winter floods already discussed, have the advantage of more vapor in the warmer tropical air and a greater intensity of convection and therefore of local storminess. The leafing out in spring, however, with increased interception and transpiration, reduces the run-off. Three floods may be cited: the general flood of April–May 1927, a very great one, and the Missouri Valley floods of May 1903, and June 1915.

In April 1927, as in early 1937, 1913, and 1882, a standing high in the southwestern Atlantic (Bermuda +0.06 inch) drove tropical air over a long fetch of very warm water [21] and into the south-central United States, where it met large flows of polar air in the middle and lower Mississippi Basin. The severe rainstorms—12 to 24 inches of rain fell in April over eastern Oklahoma, central and northern Arkansas, southern Missouri, and western Tennessee, while a large area around had more than 8 inches—following only 2 months after a midwinter flood, produced the highest stages theretofore known in the Arkansas and lower Mississippi Rivers. Frankenfield computed that about 55 cubic miles of water went down the Mississippi (26 percent of the 213 cubic miles of precipitation January to April).[22] Melted snow made a negligible contribution, as in 1937, 1922, and 1913.

The rains in April 1927 were of greater violence than in 1937, being associated frequently with thunderstorms and occasional tornadoes. In 5 days, April 10–14, 18 tornadoes occurred in connection

[21] Note the southeast-northwest isobars across the Caribbean on the North Atlantic weather maps Monthly Weather Rev., vol. 55, No. 4, charts 8–11, 1927.

[22] Frankenfield, The floods of 1927, loc. cit.: for a summary see Henry, A. J., Frankenfield on the 1927 floods in the Mississippi Valley, Monthly Weather Rev., vol. 55, pp. 437–452, 1927.

with the mixing of very cold polar air with fresh tropical air in Texas, Oklahoma, and Arkansas. Here again, as in 1937, 1913, and 1882, the coldness of the polar air was preserved by the deep snows not far to the north. The snowfall in April 1927 was tremendous on the northern Great Plains, as much as 60 inches south of the Black Hills. The cold front frequently stalled in the Ouachita or in the Ozark Mountains, as if the slight obstruction here was responsible for holding the slowly moving front. A quasi-stationary cold front here on April 19–21 yielded 5 to 12 inches of rainfall. Another period of nearly continuous rainfall was April 7–16. Analysis of the immediate cause of the rainfall showed that convergence in south winds was answerable for 43 percent, ascent over a warm front with northeast winds at the surface for 35 percent, and ascent over a cold front with northwest winds at the surface for 22 percent.[23]

The floods of May 1903 and of June 1915 in the lower Missouri, affecting Kansas City chiefly, were due to the northward thrust of tropical air by a high in the southeastern states and a westward or southwestward thrust of polar air from standing highs in the Lake region and westward. Lows stalled over the central plains and yielded tremendous quantities of rainfall in the form of great showers.[24]

FLOODS CAUSED IN PART BY OROGRAPHIC RAINFALL: APPALACHIAN AND NORTHEASTERN FLOODS OF MARCH, 1936[25]

In the floods of March 1936 the Appalachian barrier seemed to play an important role by forming the divide between banked-up polar air on the west and tropical or its underlying modified polar Pacific or polar continental air masses on the east. While this favored fairly continuous rain, glaze, sleet, and snow in successive belts westward from the divide, heavy rains fell on the east of the divide as fronts nosed northeastward under the strong tropical wind from the southeast.[26] Extraordinary rains fell where the action of these fronts was augmented by such pronounced obstructions as the White Mountains. Thus at Pinkham Notch, at 2,000 feet on the southeast slope of Mount Washington, N. H., which rises 4,300 feet above it, 6.46 inches of rain fell on March 12, while the wind on Mount Washington reached a

[23] Brooks, C. F. [and N. H. Bangs], [The causes of the flooding rains of April 1927] in discussion of Flood control with special reference to the Mississippi River, Proc. Amer. Soc. Civil Engineers, vol. 54, pt. I, pp. 1260–1265, 1928; Trans. A. S. C. E., vol. 93, pp. 894–898, 1929.

[24] Frankenfield, H. C., Floods of the spring of 1903 in the Mississippi Watershed, U. S. Weather Bur. Bull. M, 1904; Day, P. C., The weather of the month [May 1915], Monthly Weather Rev., vol. 43, pp. 250–252, 1915; Henry, A. J., The floods of May and June, 1915, in the Missouri Valley, ibid., pp. 286–287; Connor, P., Loss by floods in Kansas River and tributaries, June 1915, ibid., pp. 287–288; Henry, A. J., Rivers and floods, July 1915, ibid., pp. 353–355.

[25] Cf. U. S. Geological Survey; Water-Supply Papers 798, 799, and 800; The flood of March 1936; 466, 380, and 351 pp.

[26] Byers, H. R., Meteorological conditions during the March 1936, and other notable floods, Journ. New England Water Works Assoc., vol. 51, pp. 213–218, 9 figs., 1937.

Lichtblau, Stephen, Weather associated with floods of March 1936, U. S. Geological Survey Water-Supply Paper 800, pp. 12–31.

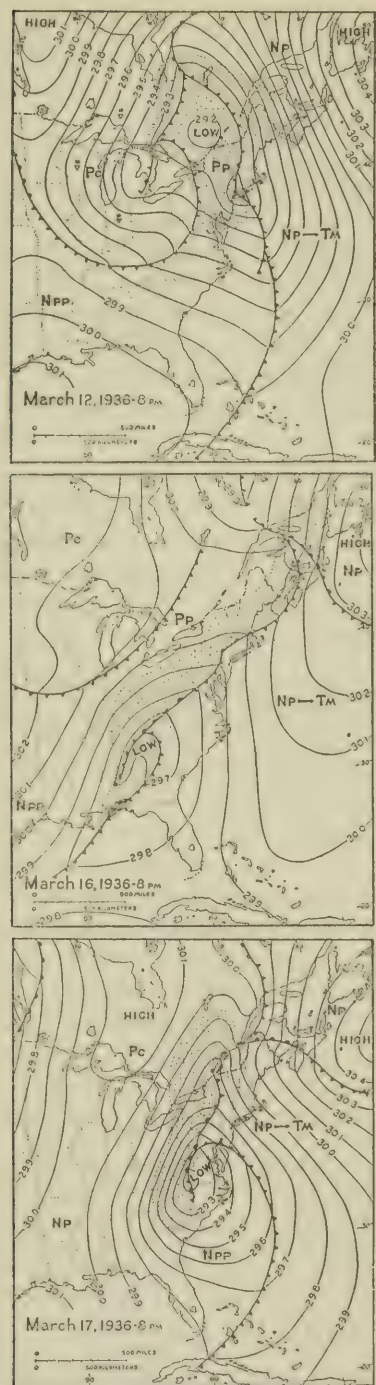


FIGURE 15.—Successive developments in the weather situation March 12 to 17, 1936, in the eastern United States (8 p. m. air-mass maps, courtesy U. S. Weather bureau).

velocity of 158 miles an hour from the south-southeast. On the 18th 6.27 inches of rain fell and 4.05 more on the 19th, while the winds on the mountain reached 132 miles an hour from the southeast. The total rainfall at Pinkham Notch in the 14 days from March 9 to 22 was 22.43 inches; at Randolph, north of the mountain, 16.19; and on the summit of Mount Washington, 13.86.

The Atlantic high on this occasion was centered off the Middle and North Atlantic States instead of Bermuda and southward as in the other three great floods. Nevertheless, the pressure at Bermuda in March 1936, averaged 0.15 inch above normal. Thus the tropical air streams reached the United States from the southeast and mostly along the coast north of Hatteras. The speed of inflow in the lower levels was often 20 to 40 miles an hour and at higher levels twice these speeds.

A complicating factor was the deep and dense snow cover and heavily frozen rivers at the beginning of March (fig. 18). Ice was reported in all the northern rivers and in the headwaters of the Ohio. The Allegheny was frozen, New Jersey rivers were ice-jammed, and the West Virginia rivers were filled with floating ice.

In January 1936 precipitation was above normal everywhere in the section of the country considered—New England, Middle Atlantic States, Virginia, and the upper Ohio Valley. Temperature everywhere averaged below normal. In the last decade of the month temperatures below zero were reported every-

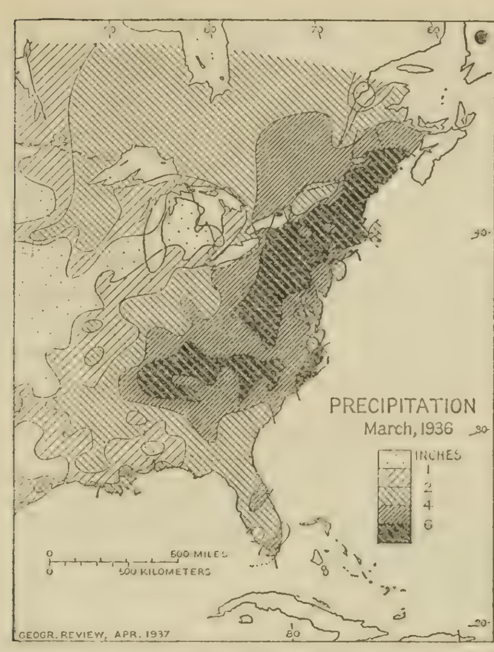


FIGURE 16.—Total precipitation in the eastern United States, March 1936. (From Monthly Weather Rev., March 1936.)

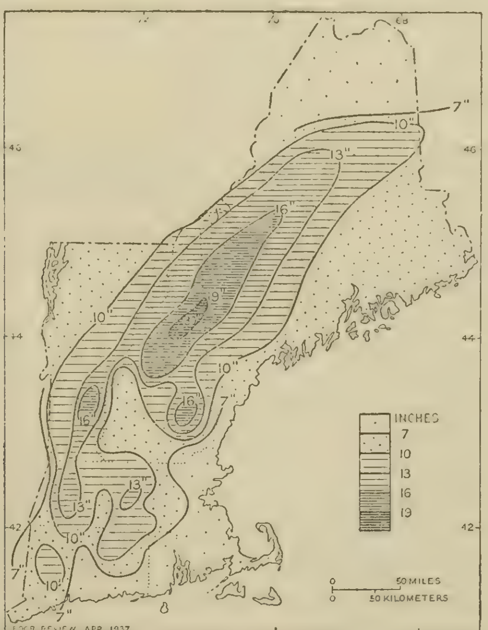


FIGURE 17.—Rainfall and water equivalent of snow cover melted from March 9 to 21, inclusive, 1936, in New England. (From Climatic Data, U. S. Weather Bureau, New England Section, March 1936.)

where from New England to Virginia and westward, including Kentucky and Ohio, and were continued in one of the coldest Februarys on record. Precipitation during February was slightly below normal for most of the area. These conditions were favorable for freezing the ground to a depth of several inches and, therefore, conducive to floods; the greater part of the March rains was immediately available as run-off. After the first 8 days, March temperatures were 3 to 12 degrees above normal. Precipitation was well above normal in all parts except Kentucky and Ohio: in New England more than twice the normal monthly amount fell. Fortunately a week of balmy winds preceded the first heavy rains, so that the removal of the snow cover and softening of the ice were well under way. A respite of a few

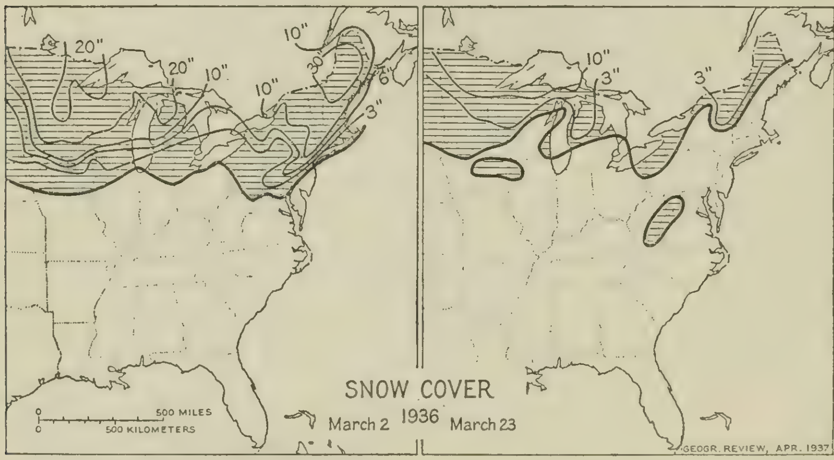


FIGURE 18.—Depth of snow on ground at 8 p. m., March 2, 1936. (From Weekly Weather and Crop Bull., March 3, 1936.)

FIGURE 19.—Depth of snow on ground at 8 p. m., March 23, 1936. (From Weekly Weather and Crop Bull., March 24, 1936.)

days after the first downpours also permitted the crest of the snow, ice block, and rain flood to pass before the greater rains descended.

Though Pittsburgh had its worst flood on record, with a stage 7 feet higher than ever before known, the local contribution to the waters was relatively small and in ice form. If the general temperatures had been only a few degrees higher, the addition of the precipitation that covered western Pennsylvania with ice or snow to the floodwaters from the 5- to 7-inch rains near the crest of the Appalachians might well have added several feet to this extraordinary visitation. The trees in a north-to-south belt across western New York were devastated by the ice storm; and Buffalo was snowed in by an unprecedented fall, to which was added a few days later another heavy snowstorm.

New England above 2,000 feet was still deeply snow-covered when the tropical wind and great rains burst upon the country on March 17;

consequently a further release of snow water added to the tremendous rain, making a total of 10 to 30 inches since March 9 (fig. 17), brought the chief rivers to unprecedented stages.[27] The headwaters in the mountains, however, were so well protected by dense coniferous forests that the snow cover was not entirely removed and acted as a good storage reservoir for the rain. At Pinkham Notch the depth of snow cover was reduced from 48 inches on the 9th to 16.2 inches on the 21st, and on Mount Washington summit from 20.5 inches to only 1 inch.[28] Accordingly, though great slush slides occurred, the floods in the mountains were not exceptional.

THE JOHNSTOWN FLOOD OF 1889

The Johnstown flood of 1889, like the flood of 1936, was caused by the meeting of a strong flow of tropical Atlantic air from the southeast with a standing front of modified though cold polar continental air near the crest of the central Appalachians.[29] Although the disaster at Johnstown and vicinity, in which some 9,000 people were drowned, was due chiefly to the bursting of a dam, the rainfall, averaging 6.2 inches over the Johnstown Valley,[30] is the outstanding occurrence of its kind over the central Appalachians.[31] The maximum was 9.8 inches, falling in 31 hours. Russell computes that 1.9 cubic miles of water fell on the Susquehanna watershed, 1 cubic mile on the Potomac, and 0.9 cubic mile on the Allegheny and Monongahela watersheds. The rain front swept from the Atlantic to Lake Erie in 16 hours.[32]

THE NEW ENGLAND AND NEW YORK FLOODS OF 1927, 1935, 1938

The New England and New York floods of November 1927 were caused in much the same manner as the widespread flood of 1936 and the less general one of 1889. The chief flood was due to the rain of November 3 to 4, when exceptional rains fell on soil thoroughly soaked by the tropical storm a fortnight before. A western low and a weak tropical cyclone joined forces in a deep current of tropical air, which was forced northward at increasing speed by a great high centered near Newfoundland. Part of the strength of this high, which at one time reached 30.72 inches, was derived from a flow of cold air from the Greenland region. The rainfall was due to convergence in the

[27] Cf. Uhl, W. F., Flood conditions in New England, Proc. Amer. Soc. of Civil Engineers, Mar., pp. 449–483, 1937; and Grover, Nathan C., The floods of March 1936, Part 1, New England rivers, U. S. Geological Survey, Water Supply Paper 798, 466 pp., illus., 1937.

[28] For further details see Baldwin and Brooks, op. cit.

[29] Byers, H. R., Meteorological conditions during the March 1936 and other notable floods, loc. cit, p. 212.

[30] Russell, T., The Johnstown flood, Monthly Weather Rev., vol. 17, pp. 117–119, 1889.

[31] Hayes, M. W., Some flood-producing storms of the Atlantic Seaboard, Journ. New England Water Works Assoc., vol. 51, pp. 207–208, 1937.

[32] Russell, op. cit., Chart 6.

tropical cyclone, to general convergence of the tropical wind in New England, to ascent, and convection touched off by it, both over highlands and a cold air mass banked up behind the Green Mountains.

With the passage of the tropical cyclone the night of the 3rd–4th, a narrow belt of excessive rain drove northward through Rhode Island and eastern Massachusetts. Orographic plus frontal effects caused more than 7 inches of rainfall in western Massachusetts and up to 9.65 in Vermont, of which 8.77 fell in one day. Still heavier rains evidently occurred in the mountains, judging from the tremendous quantities of water discharged both from the Green Mountains and from the White Mountains, possibly up to 15 inches.[33] Minor floods of the same type, occurred in Vermont and New York later in the same month.

The New England and New York floods of September 1938 resulted from a close duplication of the conditions of November 1927, only this time the tropical cyclone was a major hurricane.[34]

The New York State flood of July 1935,[35] had many features in common with the New England flood. Western New York, also a portion of Pennsylvania, received rains in excess of 8 inches in connection with a slowly moving cold front meeting active streams of tropical air, July 7–8. The maximum in 24-hours rainfall was 9.00 inches at Pottsville, Pa., 8.52 inches at Delhi, and 8.50 inches at Burdett, which had 10.50 in 2 days and 11.70 in 4. Cortland, near-by, had 11.54 inches July 7–10. Record-breaking floods occurred in spite of dry ground and low streams. Very moist tropical Atlantic and tropical Gulf air streams rapidly converged over this region and were forced upward by converging polar continental and polar Atlantic air streams in an evenly balanced action which held the polar Atlantic front with attendant thunderstorms stalled near the crest of the divide for about 24 hours.

[33] For an account of the flood in the Connecticut Valley see Goldthwait, J. W., The gathering of floods in the Connecticut River System, Geogr. Rev., vol. 18, pp. 438–445, 1928. For details as to the causes of the November floods see Weber, J. H., and Brooks, C. F., The weather-map story of the flooding rainstorm of New England and adjoining regions, November 3–4, 1927, Journ. New England Water Works Assn., vol. 42, pp. 91–103, 1928, reprinted in vol. 20, pp. 106–118, 1930. For the rainfall and comparison with other flooding storms in New England see Goodnough, X. H., Rainfall in New England during the storm of November 3 and 4, 1927, vol. 42, pp. 150–188, vol. 44, pp. 119–156, 1927. For a general account, see Frankenfield, H. C., November floods in New England and eastern New York, Monthly Weather Rev., vol. 55, pp. 496–499, maps, 1927. Cf. also Byers, loc. cit., p. 212.

[34] Brooks, C. F., Hurricanes into New England: Meteorology of the storm of September 21, 1938, Geogr. Rev., vol. 29, pp. 119–127, 1939. Cf. also Byers, loc. cit., pp. 212–213.

[35] Johnson, Hollister, The New York State flood of July 1935, U. S. Geol. Surv. Water-Supply Paper 773–E, Washington, pp. 233–268, 1936. The meteorological history of this storm was fully discussed by T. E. Reed, in the Binghamton (N. Y.) Press, July 23, 1935, maps and diagrams, and by C. L. Mitchell in Monthly Weather Rev., vol. 63, p. 231, 1935, and (reprinted) in Johnson's paper, loc. cit., in which is also a discussion by J. C. Fisher of the rainfall. Mr. Fisher also has an account in Climatological Data, U. S. Weather Bureau, New York Section, July 1935.

THE SOUTHERN APPALACHIAN AND SOUTHEASTERN FLOODS OF JULY 1916

Two slowly moving hurricanes went to pieces in the southern Appalachians July 10 and 15. The combination of exceedingly moist tropical air converging at hurricane velocities for several days over the southeastern United States produced rainfalls generally in excess of 8 inches, and over considerable areas in excess of 20. Altapass, N. C., where topography augmented normal hurricane processes in forcing air upward, recorded a fall of 22.22 inches in 24 hours.[36] Excessive though this was, it is far exceeded by the 24-hour fall of 45.99 inches, with which an 88-inch four-day rainstorm began, as a severe typhoon reached Baguio, in the highlands of Luzon, P. I., July 14–15, 1911.[37] The maximum 5- and 10-day rainfalls in 1916 were 24.45 and 31.07 inches.

CONCLUSION

Great floods may occur in the eastern United States at any time of the year, for there is always an extensive warm-water surface near by, from which great volumes of vapor may be transported, while, not far distant, throughout the year there are cold surfaces to furnish moving wedges of cold air to elevate the tropical air. The polar air masses engage the tropical masses normally every few days, and rains fall. The great floods occur, however, only when a persistent high over the western Atlantic sends the tropical air inland for days in succession, and then only when the polar masses meet and elevate the tropical air over the same area or region for one to several days in succession or on repeated occasions. Topography plays an important role in determining where slowly moving fronts will stall: sometimes even minor divides are effective. Snow cover seldom contributes much to great floods, though by helping to keep cold air masses cold it may contribute to stalling and to the maintenance of the temperature contrast between the cold and the warm air masses.

What can man do about great floods?[38] He cannot change the amount of rain that will fall; but he can change the rate at which it will run off. He cannot change the amount of snow that will fall; but by dense evergreen foliage he can hinder it from reaching the ground and, once on the ground, from being converted into rapid run-off. Once the water is running off, he can hold back some of it by numerous dams on small streams and by larger dams below; and, by adequate

---

[36] Henry, A. J., Floods in the East Gulf and South Atlantic States, July 1916. Monthly Weather Rev., vol. 44, pp. 466–476, 1916.

[37] Cf. Co-Ching Chu, Distribution of precipitation in China during the typhoons of the summer of 1911. Monthly Weather Rev., vol. 44, p. 446, 1916.

[38] A symposium on recent eastern floods and the national aspects of flood control held in Pittsburgh October 13 and 14, 1936, is summarized in Civil Engineering, vol. 7, pp. 25–32, 1937, and published in full in the March issue of Proceedings of the American Society of Civil Engineers.

measurements of rainfall and condition of the ground and by a rapid system of collecting reports, he can compute in advance when and how high the waters will rise. He can confine the rivers by levees, but he must provide for temporary diversion of excess waters over capacious lowlands. He can straighten the stream channels to hasten the water on its way but, without great care, such relief upstream may mean a greater flood downstream. The operation of control dams and diversions could be more intelligently directed if great rains could be foreseen more than a day or two in advance. This is not impossible, and studies in long-range forecasting are already rather promising. But whatever success may be attainable in weather and river-stage forecasting the main point to bear in mind is that 10-inch rains do fall, sometimes in a few hours, and that if man does not control the speed with which the water reaches the streams and then whither it goes floods will devastate the valleys.

EYES THAT SHINE AT NIGHT

By Ernest P. Walker
Assistant Director, National Zoological Park

[With one plate]

The "shining" of eyes at night by the reflection of light is a common and generally fairly well known natural phenomenon of which little has been recorded except incidentally in accounts of hunting and of campfire scenes. The shining of the cat's eyes at night by reflected light is probably the best known of all eye reflections. The eyes of human beings very rarely shine. There are, however, occasional reports of the shining of a human being's eyes, and I have heard of one instance of a person being shot at night because his eyes shone. These, however, I have not verified.

While studying the condition and activity of small mammals in the recently completed Small-Mammal House in the National Zoological Park, I became interested in the different kinds of reflections obtained from the eyes of different animals and proceeded to make inquiry from naturalists and to search for literature on the subject.

In A Survey of Nocturnal Vertebrates in the Kartabo Region of British Guiana, Crawford [1] refers to the glow of eyes and lists the kinkajou, jaguar, puma, ocelot, yaguaroundi, margay, opossum, three species of toads of the genus *Bufo*, and the giant goatsucker *Nyctibius*. He does not refer to the colors and does not mention the caimans which inhabit that general region and whose eyes give perhaps the most pronounced and beautiful glow I have observed.

A. J. Van Rossem [2] lists 28 species of birds observed by him or recorded by others as "shining." He also refers to light reflections from the eyes of insects, spiders, and domestic animals. In this paper he lists 3 manuscripts and 5 publications recording eye shines, and brings out points that should be studied by future students of the subject. No other published material on the shining of the eyes of vertebrates has come to my attention.

Examinations of the eyes of various animals as well as those of man by use of the opthalmoscope have been made by several writers, notably Johnson [3] and Wood.[4] Both authors picture the surface of the

[1] Crawford, S. C., A survey of nocturnal vertebrates in the Kartabo region of British Guiana. Journ. Animal Ecol., vol. 2, p. 282, November 1933.

[2] Van Rossem, A. J., Eye shine in birds, with notes on the feeding habits of some goatsuckers. The Condor, vol. 29, pp. 25–28, January 1927.

[3] Johnson, G. L., Contributions to the comparative anatomy of the mammalian eye, chiefly based on ophthalmoscopic examination. Proc. Roy. Soc. London, ser. B, vol. 194, 1901.

[4] Wood, C. A., The fundus oculi of birds, especially as viewed by the ophthalmoscope. Chicago, 1917.

retina as revealed to them through the opthalmoscope. These pictures, however, might be compared to the view that would be obtained by standing outside a dark room and projecting a beam of light onto the walls of the room, thereby revealing the color and other features of the walls to the observer standing outside. This is quite different from the "shining" of eyes, which merely brings back toward the observer diverging rays of colored light like small incandescent lights seen from a distance.

Information on the "shining of eyes" is so meager that it appears justifiable to record my observations in the hope that someone may be able to use them as a foundation for further studies. While eyes of animals in the wild are frequently observed at night, the name of the owner of the eyes is often unknown, and there is little likelihood that the same individual can be observed again under similar conditions. A zoo is unexcelled for this purpose as it permits one to study many different kinds of animals under more or less constant conditions and to observe repeatedly the same individuals.

In obtaining my observations I used a reflecting head lamp, similar to a hand flashlight, worn on my forehead connected by a cord to a three-cell battery in a pocket or on my belt. Flashlights carried in the hand were used at times but were not entirely satisfactory as the rays of the light must closely parallel the line of sight of the observer in order to obtain reflections from the greatest number of species and uniform results. The best results are obtained with a light of moderate intensity. If it is too bright, the shining is less conspicuous or does not show at all. Four main points are observable in every case. They are:

(*a*) Whether or not the eyes reflect light.

(*b*) If they reflect, the color of the reflection and whether the color is individually constant or variable; also whether or not it varies in different individuals of a species.

(*c*) Whether the reflection is dull, medium, or brilliant.

(*d*) The angle from which reflections are obtainable, i. e., whether it is necessary for the observer to be opposite the center of the eye, or if the reflection can be obtained from behind the animal and in front of it, as well as directly opposite the center of the line of vision. This might be considered as wide or narrow angle of reflection.

For the sake of brevity the data given in the appended list relates almost entirely to observations on (*b*) and (*c*).

The description of colors in words and the indication of varying degrees of brilliance or paleness are so difficult that the observations herein recorded can in general indicate only relative differences between animals.

The word "glow" is sometimes used to describe the character of the reflections. This term can well be used for the reflections given

off by the eyes of alligators, crocodiles, and caimans; "shining" their eyes gives one the impression that he is looking into a brilliantly glowing pinkish opening in a dull surfaced bed of coal. In the majority of mammalian eyes observed I have gained the impression of looking at a highly polished metal surface. Sometimes the effect is likened to looking into an incandescent globe of the color indicated. Often pronounced light rays appear to emanate from the eyes. In some eyes, such as those of the smaller rodents, the effect is that of looking into an illuminated piece of amber.

To assist the reader to understand the character of the reflections, a colored drawing has been prepared for a few animals, to show some of the range of reflections obtained. Efforts were made to produce a plate that would show not only the colors but the glow or brilliance of the eyes, but several artists were unable to produce the effect even on an original and, had they done so, it is doubtful whether it could have been reproduced. The proper effect could undoubtedly be well simulated by placing small incandescent lights behind translucent spots of the right color on an opaque background. Indeed, the brilliance of the reflections is as impossible to show as is the gleam from snow in sunlight. At my suggestion, Mr. Fred Adams of the Dufaycolor, Inc., New York City, experimented in taking a few color pictures by photoflash. The results as to eye shine, though not entirely satisfactory, are promising.

The illustration shows the eyes in pairs, and as disks. Frequently, however, only a single eye is seen, or in some instances, depending on the position, both eyes are seen as ovals or crescents, or other modifications of a true circle. In practically all species, however, it is possible to obtain the shine in both eyes simultaneously to some extent, even though they are not perfect circles.

A confusing factor is the circumstance that different persons apparently see the reflections as quite different colors. One person who is usually good in recognizing colors by daylight insists that the reflections are without color. Others have described or painted for me their conception of some of the reflections much more reddish than I see them.

I have made no experiment designed to prove which surface of the eye produces the reflections. In the case of the animals that have eyes that "glow" or are like amber it appears that we look into the eye through the pupil as if the reflection came from the front surface of the retina. In those animals that give a reflection as from polished metal I gain no impression of looking into the eye. In most of these cases, however, the reflection is not obtainable closer than 8 to 20 feet—a distance that prevents one from observing which surface reflects. The reflections of alligators, crocodiles, and caimans can be seen when the observer is within a foot of the animal. In

most animals, other than man and the higher primates, the retina has an extra coat or layer, the *tapetum lucidium.* This may be the reflecting surface.

The editor of the Journal of the Bombay Natural History Society (vol. 31, No. 1, p. 221) makes a brief comment regarding a short article by A. A. Dunbar Brander relative to the source of color in the eye of the gaur, which reads:

> In volume IV of the Society's Journal the late Mr. J. D. Inverarity came to the same conclusion as Mr. Dunbar Brander and pointed out that the blue colouring of the gaur's eye is due to the *tapetum lucidium*—the lining to a greater or less extent of the back part of the choroid membrane of the eye which, in the gaur, is of a lovely peacock-blue color. It is this membrane which causes an animal's eye to shine in the dark. In the human eye it is opaque and black.

The eyes of most domesticated and some wild animals deteriorate in captivity so that the vision may become very poor. Defective eyes have been apparent in a few of the cases observed.

At the suggestion of Dr. Earl S. Johnston, of the Smithsonian Institution, Division of Radiation and Organisms, beams of red and blue light have been projected into the eyes. These rays were obtained by fastening a single thickness of red or blue Cellophane over the flashlight lens. Over 40 species of mammals, reptiles, and amphibians were examined under the red rays, but there was very little variation in colors of the reflected light from various animals other than the addition of a red tinge. They varied from a dull reddish amber through reddish silver to reddish gold, the differences being mainly those of brilliance. Observations on 30 species of mammals and reptiles gave similar results with blue rays, the reflections ranging from dull and pale bluish silver to blue-green and blue, with the metallic luster persisting in those species that give brilliant reflections under normal light. The reflections from the crocodilians were partially opalescent. The characteristics of the responses to colored lights indicate that fluorescence does not account for the response to the rays of the torch. Reflection is left as the only probable source of the return light.

In some animals the color of the "shine" is constant whereas in others it may appear as three different colors in a few seconds, while in some instances the color is constant for each observation but may be different on different days.

It has been suggested that the change is caused by the animal's changing the direction of its eyes. In some cases this is true, but in others I have been unable to detect any change in the position of the eye, and since most animals change their line of sight mainly by moving the head rather than rolling the eyes it is probable that a change that would alter the reflected light would be detected in movement of the head. Most of the bears that I have observed swing their heads from side to side without changing the color of the reflections from their eyes.

A few animals, notably the binturong and the golden cat, close their eyes very quickly when the beam of light is directed at them. Most, however, stare directly at the light or move the head only slightly.

Of the monkeys, no shine was detected from the eyes of orangutans, chimpanzees, gibbons, macaques, langurs, baboons, and marmosets. A faint suggestion of a shine was detected in the ring-tailed lemur. On the other hand, the eyes of the slow loris and the potto gave the most brilliant reflections of all eyes observed. Mr. A. J. Van Rossem once told me he had seen the eyes of spider monkeys shine.

My observations suggest that the majority of rodent eyes shine but dully in browns, hazel or amber, but the porcupines are an exception—their eyes are very brilliant—generally silvery and reflecting through a wide angle.

In the case of snakes, one is sometimes tempted to mistake the shine from the surface of the scale over the eye (the brille) for the true reflection of the eye.

These studies have been more fruitful of unsolved questions than of answers. Some of the questions are:

1. Do the animals possess vision over a wide cone or only over that cone in which reflections may be obtained? If the former is the case, it indicates that such animals as the hippopotamus and Old World porcupines can see in practically any direction except for a narrow angle directly behind them. Others have a very narrow angle of vision.
2. What is the difference between eyes that shine and those that do not?
3. What produces the different colors of reflections?
4. What changes take place in an eye that cause it to give differently colored reflections in quick succession?
5. What is the explanation of the fact that eyes that do not change colors quickly give quite different colored reflections on different dates?
6. Why do some eyes that give reflections at a distance beyond 8 to 10 feet fail to give any when viewed at a lesser distance?

In the following list the occurrence of the letters C., or C. and E., indicate that the observations were made by Jeremiah A. Collins or Collins and Arthur L. Edwards, National Zoological Park policemen, while on night duty. This opportunity is taken to thank them for their assistance. The mark / between notes indicates different dates of observation. Some of the animals have been observed many times. The figures in parentheses indicate the number of individuals observed.

MAMMALS

MARSUPIALIA

DIDELPHIDAE:

Virginia opossum (*Didelphis virginiana*) ------- Dull orange.

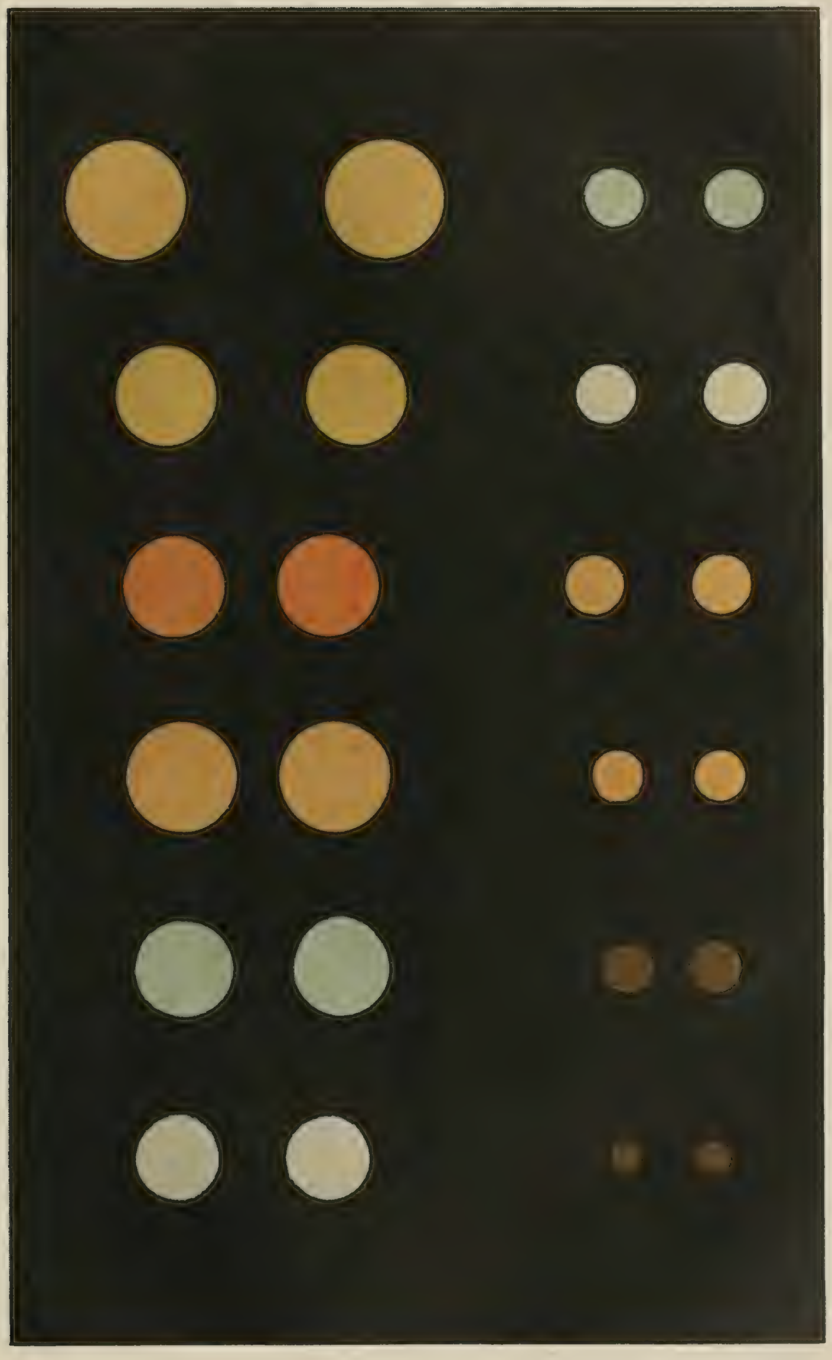
Zorro or banana opossum (*Metachirus opossum*) ------- Silvery to pale amber.

MACROPODIDAE:

Tree kangaroo (*Dendrolagus inustus*) (2) ------ Dull deep red amber. / Deep reddish orange. / Red dish orange and blood red.

EXPLANATION OF PLATE 1

Golden cat *Profelis temmincki*	Small-toothed palm civet *Paradoxurus hermaphrodytus*
Javan mouse deer *Tragulus javanicus*	Do. (Same individual)
Alligator *Alligator mississipiensis*	Do. (Same individual)
Slow loris *Nycticebus coucang*	Prehensile-tailed porcupine *Coendou prehensilis*
Lesser tiger cat *Felis pardinoides*	Kangaroo rat *Dipodomys merriami*
Malay porcupine *Acanthion brachyurum*	Great Basin pocket mouse *Perognathus parvus*



SOME ANIMAL EYES THAT SHINE AT NIGHT.

Reproduction of painting by Mrs. Helen Conger, W. P. A. artist, from direct observations.

CARNIVORA

FELIDAE:	
Cheetah (*Acinonyx jubata*)	Green. C.
Puma (*Felis concolor*) (3)	Pale green to silvery-gold.
Lion (*Felis leo*)	Golden. C.
Uganda wild tabby (*Felis ocreata*)	Green changing to slightly golden. / Green then silvery.
Jaguar (*Felis onca*)	Golden. C.
Ocelot (*Felis pardalis*)	Bright golden. C.
Lesser tiger cat (*Felis pardinoides*) (1)	Green with occasional silvery tinge. Reflection obtained when rays are at a wide angle from eye.
East African leopard (*Felis pardus suahelicus*)	Green. C.
Siberian tiger (*Felis tigris longipilis*) (2)	Pale green. / Silver. C.
Caracal (*Lynx caracal*)	Greenish gold.
Bay lynx (*Lynx rufus*) (2)	Green and silvery.
Bay or golden cat (*Profelis temmincki*) (2)	Dull orange. / Silvery. / Repeatedly observed, usually pale golden.
VIVERRIDAE:	
Binturong (*Arctictis binturong*)	Green changing to salmon pink then yellow. / Yellow. / Silvery to golden, but shut eyes quickly. / Brilliant silver and light green. / Opalescent.
Civet (*Civettictis civetta*)	Pale green, silver, orange, depending on angle.
Neumann's genet (*Genetta dongalana neumanni*)	Pale green and silver. / Clear light green.
Civet (*Moschothera megaspila*)	Silver, yellow, and occasional green.
Palm civet (*Paradoxurus hermaphrodytus*) (3)	Green, then amber. / Pale blue-green then golden. / Golden and silver. / Green, then golden, then silver. 1 dull and 1 brilliant. / Green then golden.
CANIDAE:	
Coyote (*Canis latrans*) (4)	Brilliant golden. / Golden. / Golden and light greenish. / Constant brilliant blue-green. / Green and silvery.
Albino coyote (*Canis latrans*) (2)	Golden and greenish. / Very small, variable orange to silvery and green.
Timber wolf (*Canis lupus lycaon*)	Green, then silvery.
Wolf (*Canis lupus nubilus*) (5)	Orange, silvery, and green. / Orange, golden, and occasional green.
Wolf and dog hybrid (*Canis lupus nubilus* × *domesticus*)	Usually light golden silvery. Occasionally green.
Texas red wolf (*Canis rufus*) (7)	Variable. Brilliant golden, sometimes tinged with reddish. Sometimes silvery. Often blue-green. Changes due to position.
Maned wolf (*Chrysocyon jubata*)	Golden. C.
Sumatran wild dog (*Cuon javanicus sumatrensis*)	Green. C.
Red fox (*Vulpes fulva*) (4)	One animal with one large brilliant reddish gold eye and one very small and dull. Three others faint greenish silvery; silvery and golden; all brilliant.
PROCYONIDAE:	
Gray coatimundi (*Nasua narica*) (2)	Blue green, silvery to gold. / Green and silvery.
Kinkajou (*Potos flavus*) (3)	Light bright gold; golden, then green. / Brilliant deep gold, occasionally with green tinge. / Golden. / Brilliant orange to gold. Slight difference between 2 animals observed.
Black raccoon (*Procyon lotor*) (3)	Medium amber. / Pale green. / Silvery and later light yellow. Did not shine, then green.
Albino raccoon (*Procyon lotor*) (1)	Very pale yellow.
Normal raccoon (*Procyon lotor*)	Very pale yellow.
BASSARISCIDAE:	
Ring-tail or cacomistle (*Bassariscus astutus*) (2)	Green, silvery, orange.
MUSTELIDAE:	
Hog badger (*Arctonyx collaris*) (2)	Brassy to silvery. Fairly brilliant. / Silver to light gold.
Asiatic marten (*Charronia flavigula henricii*)	Blue-green. / Green. / Green.
White tayra (*Galictis barbara barbara*) (2)	Dull silvery to light orange.
Alaskan otter (*Lutra canadensis*)	Light amber.
Florida otter (*Lutra canadensis vaga*)	Silvery to amber. / Silver. / Brilliant pale yellow both in water and out.
Skunk (*Mephitis nigra*) (4)	Bright deep amber. / Gold.
Small-clawed otter (*Micraonyx leptonyx*)	Pale yellow to light amber. / Light golden to silvery.
Ferret (*Mustela eversmanni*)	Blue-green to silver.
Mink (*Mustela vison vison*)	Yellow and green.
Florida spotted skunk (*Spilogale ambarvalis*)	Very light amber. / Silver to light amber.

114728—39——24

CARNIVORA—Continued

URSIDAE:	
Glacier bear (*Euarctos emmonsii*)	Silver tinged with golden.
Polar bear (*Thalarctos maritimus*)	Silver tinged with very pale blue. Like a star.
Hybrid bear (*Thalarctos maritimus* × *Ursus gyas*) (3)	Greenish silvery and blue-green.
Kidder's bear (*Ursus kidderi*)	Golden-silvery to deep gold.
PINNIPEDIA	
OTARIIDAE:	
California sea lion (*Zalophus californianus*)	Very dull pale amber.
PHOCIDAE:	
Pacific harbor seal (*Phoca richardii*) (2)	Golden.
PRIMATES	
CALLITRICHIDAE:	
Black-tailed marmoset (*Mico argentata*)	None.
CERCOPITHECIDAE:	
Javan macaque (*Macaca mordax*)	None.
LEMURIDAE:	
Ring-tailed lemur (*Lemur catta*) (2)	Dull pale amber. / One golden and one light gold. / Golden.
Slow loris (*Nycticebus coucang*) (3)	Brilliant amber. / Brilliant deep red amber. / Brilliant deep red gold. / Deep amber. / Amber.
Potto (*Perodicticus potto*)	Brilliant faint-greenish to very pale lemon.
RODENTIA	
SCIURIDAE:	
Sumatran tricolored squirrel (*Callosciurus melanops*) (2)	Dull pale amber.
Albino woodchuck or groundhog (*Marmota monax*)	Orange.
Javan giant squirrel (*Ratufa bicolor*)	Red amber.
Rock squirrel (*Ratufa* sp.)	Dull deep orange.
Lesser white squirrel (*Sciurus finlaysoni*) (6).	Dull pale amber. / Light golden.
Hoffman's squirrel (*Sciurus hoffmani* sub. sp.) (2)	Dull light brown.
Fox squirrel (*Sciurus niger*, dark phase)	Red amber. / Deep orange.
HETEROMYIDAE:	
Merriam's silky pocket mouse (*Perognathus merriami merriami*) (2)	Medium amber, medium bright.
JACULIDAE:	
Egyptian jerboa (*Jaculus jaculus*) (5)	Pale amber. / Very pale amber.
CRICETIDAE:	
Woodrat (*Neotoma micropus*)	Pale yellow amber. / Light dull amber.
White-footed mouse (*Peromyscus leucopus*) (2)	Dull amber. / Dull amber.
Cotton rat (*Sigmodon hispidus*)	Dull deep amber.
MURIDAE:	
Gambia pouched rat (*Cricetomys gambianus*) (2)	Dull orange.
Bamboo rat (*Notocleptes sumatrensis*)	Pale amber. / None.
Grasshopper mouse (*Onychomys leucogaster*)	Dull amber.
DIPODIDAE:	
Kangaroo rat (*Dipodomys merriami*)	Dull pale amber.
Kangaroo mouse (*Microdipodops pallidus*)	Dull pale amber.
HYSTRICIDAE:	
Malay porcupine (*Acanthion brachyurum*) (3)	Brilliant silvery orange (reflect in scant light). / Bright light silver. Reflect at wide angle from light source and over wide angle.
African brush-tailed porcupine (*Atherurus africana*) (2)	Very bright silver to very pale yellow.
East African porcupine (*Hystrix galeata*) (2)	Medium amber. / Orange when first awakened; silvery.
Brush-tailed porcupine (*Thecurus sumatrae*) (2)	Brilliant silvery. Shine in scant light.
ERETHIZONTIDAE:	
Prehensile-tailed porcupine (*Coendou prehensilis*)	Light orange. Visible from very wide angle. / Golden to light yellow both close up and at a distance.
MYOCASTORIDAE:	
Coypu rat (*Myocastor coypu*) (2)	Dull silver tinged with gold.

RODENTIA—Continued

CAPROMYIDAE:

Hutia (*Capromys pilorides*) (8) — Dull medium amber. / Deep reddish orange. / Deep golden or reddish orange.

CUNICULIDAE:

Central American paca (*Cuniculus paca virgatus*) — Dark red amber, moderate brilliance. / Deep golden.

DASYPROCTIDAE:

Agouti (*Dasyprocta croconota prymnolopha*) (2) — Dull orange.

HYDROCHOERIDAE:

Capybara (*Hydrochoerus hydrochoerus*) — Dull hazel. / Brown eye but no reflection.

LAGOMORPHA

LEPORIDAE:

Varying hare or snowshoe rabbit (*Lepus americanus*) — Medium amber, medium brilliance. / Orange.

ARTIODACTYLA

BOVIDAE:

Aoudad (*Ammotragus lervia*) — Silver. C.

Anoa (*Anoa depressicornis*) — Brownish red. C.

Gaur (*Bibos gaurus*) (2) — Brilliant gold. / Silver. C.

Gayal (*Bos frontalis*) — Gold. C.

White-tailed gnu (*Connochaetes gnu*) (2) — Brilliant greenish-silver.

African buffalo (*Synceros caffer*) (2) — Bright silvery greenish gold. / Silver. C.

TRAGULIDAE:

Javan mouse deer (*Tragulus javanicus*) — Copper, silvery, pale green. / Brilliant silvery with pale blue-green tinge. / Greenish silver, then golden. Reflects over wide angle and when light is directed at wide angle. Brilliant.

CERVIDAE:

Axis deer (*Axis axis*) — Silvery with faint greenish tinge. / Pale amber.

Barasingha deer (*Cervus duvaucellii*) — Green, silver, and gold.

Barking deer (*Muntiacus javanica*) — Golden. C.

Barking deer (*Muntiacus sinicus*) — Female, 1 eye gold, 1 eye silver. C.

CAMELIDAE:

Llama (*Lama glama*) — Orange. / Orange.

GIRAFFIDAE:

Giraffe (*Giraffa camelopardalis*) (4) — Greenish silvery gold. / Bright silver. C.

HIPPOPOTAMIDAE:

Pigmy hippopotamus (*Choeropsis liberiensis*) — Gold (wide angle). / Brownish red. C.

Hippopotamus (*Hippopotamus amphibius*) — Gold (very wide angle). / Gold. C.

PERISSODACTYLA

EQUIDAE:

Asiatic wild ass or kiang (*Equus onager*) — Silvery, pale amber. Wide angle. / Silver.

Mongolian wild horse (*Equus przewalskii*) — Silver. / Silvery, pale amber.

Chapman's zebra (*Equus quagga chapmani*) — Brilliant silver with gold tinge. / Silver. C.

Mountain zebra (*Equus zebra*) — Dull silver.

TAPIRIDAE:

Asiatic tapir (*Acrocodia indicus*) — Brilliant gold. / Brownish red. C.

Baird's tapir (*Tapirella bairdii*) — Brilliant gold. / Brownish red. C.

Brazilian tapir (*Tapirus terrestris*) — Ruby red. C.

RHINOCEROTIDAE:

Black rhinoceros (*Diceros bicornis*) — Dull red. C.

PROBOSCIDEA

ELEPHANTIDAE:

Sumatran elephant (*Elephas sumatranus*) — Red. C.

African elephant (*Loxodonta africana oxyotis*) — Pale silvery. / Red. C.

EDENTATA

CHOLOEPODIDAE:

Two-toed sloth (*Choloepus didactylus*) — Bright red. C.

DASYPODIDAE:

Six-banded armadillo (*Dasypus sexcinctus*) — Light dull brown.

BIRDS

CASUARIIFORMES

CASUARIIDAE:

Cassowary (*Casuarius* sp.) — Amber. C.

CASUARIIFORMES—Continued

DROMICEIIDAE:
- Common emu (*Dromiceius novaehollandiae*) ---- Dull amber.

SPHENISCIFORMES

SPHENISCIDAE:
- Jackass penguin (*Spheniscus demersus*) -------- Gold. C.

PELECANIFORMES

PHALACROCORACIDAE:
- Flightless cormorant (*Nannopterum harrisi*) --- Dull pale amber.
- Farallon cormorant (*Phalacrocorax auritus albociliatus*) -------- Brilliant silver.
- Florida cormorant (*Phalacrocorax auritus floridanus*) -------- Gold. C.

FREGATIDAE:
- Lesser frigate bird (*Fregata ariel*) -------- Silver. C.

CICONIIFORMES

ARDEIDAE:
- American egret (*Casmerodius albus egretta*) --- Silver. C.
- Snowy egret (*Egretta thula*) -------- Gold and silver. C.
- Louisiana heron (*Hydranassa tricolor ruficollis*) - Gold and silver. C.
- Black-crowned night heron (*Nycticorax nycticorax naevius*) -------- Silver.

COCHLEARIIDAE:
- Boatbill heron (*Cochlearius cochlearius*) -------- Silvery pale gold. Ruby red. C.

BALAENICIPITIDAE:
- Shoe-bill stork (*Balaeniceps rex*) -------- Amber. C.

SCOPIDAE:
- Hammerhead (*Scopus umbretta*) -------- Silver. C.

CICONIIDAE:
- Woolly-necked stork (*Dissoura episcopus*) ----- Silver. C.
- Saddle-billed stork (*Ephippiorhynchus senegalensis*) -------- Bright gold. C.
- Malay stork (*Ibis cinereus*) -------- Silver. C.
- Indian adjutant (*Leptoptilus dubius*) -------- Gold. C.

THRESKIORNITHIDAE:
- Roseate spoonbill (*Ajaia ajaja*) -------- Ruby red. C.

PHOENICOPTERIDAE:
- Chilean flamingo (*Phoenicopterus chilensis*) ---- Ruby red. C.

ANSERIFORMES

ANATIDAE:
- Wood duck (*Aix sponsa*) -------- Silvery gold.
- Black-bellied tree duck (*Dendrocygna autumnalis*) -------- Gold to silver. C.

FALCONIFORMES

CATHARTIDAE:
- California condor (*Gymnogyps californianus*) -- Faint pale gold.

ACCIPITRIDAE:
- Red-tailed hawk (*Buteo borealis*) -------- No reflection. / None.
- Red-shouldered hawk (*Buteo lineatus*) -------- Faint silvery.

GALLIFORMES

MEGAPODIIDAE:
- Molucca megapode (*Megapodius freycineti*) ---- Gold. C.

CRACIDAE:
- Panama curassow (*Crax rubra*) -------- Bright gold. C.

PHASIANIDAE:
- Chukar partridge (*Alectoris graeca*) -------- Gold. C.
- Argus pheasant (*Argusianus argus*) -------- Silver. / Bright gold. C.
- Cheer pheasant (*Catreus wallichii*) -------- Gold. C.
- Migratory quail (*Coturnix coturnix*) -------- Silver. C.
- Jungle fowl (*Gallus gallus*) -------- Gold. C.
- Green peafowl (*Pavo muticus*) -------- Bright gold. C.
- Ring-necked pheasant (*Phasianus torquatus*) -- Silvery to pale brass.

Gruiformes

GRUIDAE:

Demoiselle crane (*Anthropoides virgo*) ---------- Silvery to pale brass. / Gold. C.
Sandhill crane (*Grus canadensis tabida*) -------- Silvery to pale brass.

PSOPHIIDAE:

Gray-backed trumpeter (*Psophia crepitans*) --- Amber. C.

RALLIDAE:

New Zealand mud hen (*Porphyrio melanotus*) -- Silver. C.
Gray-headed porphyrio (*Porphyrio poliocephalus*) ---------- Silver. C.

Charadriiformes

HAEMATOPODIDAE:

European oyster catcher (*Haematopus ostralegus*) ---------- Gold. C.

CHARADRIIDAE:

South American Lapwing (*Belonopterus cayennensis*) ---------- Silver. C.

LARIDAE:

Silver gull (*Larus novaehollandiae*) (50) -------- No shine. / No shine.

Columbiformes

COLUMBIDAE:

Nicobar pigeon (*Caloenas nicobarica*) ---------- Silver. C.
Archangel pigeon (*Columbia livia*) (domestic) -- Gold. C.
Victoria crowned pigeon (*Goura victoria*) ------ Gold. C.

Psittaciformes

PSITTACIDAE:

Yellow-naped parrot (*Amazona auropalliata*) -- Gold. E. and C.
Double yellow-head parrot (*Amazona oratrix*) -- Gold. E. and C.
Illiger's macaw (*Ara maracana*) --------------- Gold. E. and C.
Mexican green macaw (*Ara mexicana*) --------- Gold. E. and C.
Banksian cockatoo (*Calyptorhynchus magnificus*) ---------- Silver. E. and C.
Sulphur-crested cockatoo (*Kakatoe galerita*) ---- Silver. E. and C.
Leadbeater's cockatoo (*Kakatoe leadbeateri*) ---- Silver. E. and C.
Slender-billed cockatoo (*Kakatoe tenuirostris*) -- Silver. E. and C.
Cockatiel (*Leptolophus novaehollandicus*) ------ Gold. E. and C.
Quaker paroquet (*Myopsita monachus*) ------- Gold. E. and C.
Kramer's paroquet (*Psittacula krameri*) ------- Gold. E. and C.
Long-tailed paroquet (*Psittacula longicauda*) --- Gold. E. and C.

Strigiformes

STRIGIDAE:

Great horned owl (*Bubo virginianus*) ---------- Orange, medium brilliance. / Different individuals: greenish silvery gold; medium brilliance; golden red.
Screech owl (*Otus asio*) ---------------------- Ruby red.
Barred owl (*Strix varia*) ---------------------- Orange, brilliant. / Fairly brilliant deep gold.

Caprimulgiformes

PODARGIDAE:

Tawny frogmouth (*Podargus strigoides*) ------- Ruby red. C.

Coraciiformes

ALCEDINIDAE:

Kookaburra (*Dacelo gigas*) -------------------- Gold. C.

MOMOTIDAE:

Motmot (*Momotus momotus parensis*) --------- Gold. C.

BUCEROTIDAE:

Long-crested hornbill (*Berenicornis comatus*) -- Amber. C.
Rhinoceros hornbill (*Buceros rhinoceros*) ------ Green gold. C.
Abyssinian ground hornbill (*Bucorvus abyssinicus*) ---------- Gold. C.
Concave casque hornbill (*Dichoceros bicornis*) -- Gold. C.
Pied hornbill (*Hydrocissa convexa*) ------------ Silver. C.

PICIFORMES

RAMPHASTIDAE:

- Toco toucan (*Ramphastos toco*) ---- Silver. C.

PASSERIFORMES

CORVIDAE:

- American crow (*Corvus brachyrhynchos*) ---- Silver. C.
- Australian crow (*Corvus coronoides*) ---- Silver. C.

PARADISEIDAE:

- Lesser bird of paradise (*Paradisea minor*) ---- Gold. C.
- Red bird of paradise (*Paradisea rubra*) ---- Gold. C.
- 12-wired bird of paradise (*Seleucides niger*) ---- Gold. C.

STURNIDAE:

- Glossy aplonis (*Aplonis chalybea*) ---- Ruby red. C.

ICTERIDAE:

- Cuban red-winged blackbird (*Agelaius assimilis*) ---- Silver. C.

REPTILES

LORICATA

CROCODYLIDAE:

- Alligator (*Alligator mississipiensis*) (15) ---- Brilliant pinkish orange glow.
- Caiman (*Caiman sclerops*) (3) ---- Very brilliant pinkish orange glow. Effect of looking far into the eye.
- West African crocodile (*Crocodylus cataphractus*) (1) ---- Brilliant pinkish orange glow.
- Salt-water crocodile (*Crocodylus porosus*) ---- Pinkish orange glow.
- Broad-nosed crocodile (*Osteolaemus tetraspis*) ---- Brilliant pinkish orange glow.
- Malayan gavial (*Tomistoma schlegeli*) ---- Pinkish orange glow.

SQUAMATA

No satisfactory shine observed from any of about 25 species of lizards.

OPHIDIA

BOIDAE:

- Green tree boa (*Boa canina*) ---- Brilliant lemon.
- Cook's tree boa (*Boa cooki*) ---- Bright orange.

COLUBRIDAE:

- Pike-headed tree snake (*Oxybelis acuminatus*) ---- Pale golden, fairly bright.

CROTALIDAE:

- Copperhead (*Agkistrodon mokasen*) ---- Faint glisten.

VIPERIDAE:

- Gaboon viper (*Bitis gabonica*) ---- Dull pale silver.

AMPHIBIA

SALIENTIA

BUFONIDAE:

- Sapo de concha (*Bufo empusus*) ---- Dull pale orange.
- Cuban giant toad (*Bufo peltocephalus*) ---- Amber, medium brilliance.
- Leaf toad (*Bufo superciliosus*) ---- Amber.

CERATOPHRYDAE:

- Horned toad (*Ceratophrys dorsata*) ---- Brilliant medium amber.

HYLIDAE:

- Australian tree frog (*Hyla caerulea*) ---- Brilliant pale amber.
- Cuba tree frog (*Hyla septentrionalis*) ---- Deep amber, medium brilliance

FISHES

Zebra fish (*Brachydanion rerio*) ---- Brilliant silver.

THE CHINESE MITTEN CRAB

By A. PANNING,
Hamburg, Germany

[With nine plates]

PREFACE

The assumption that animals settle in new lands beyond the borders of their native habitats and thus extend the range of their habitation often plays an important part in zoogeography. Such assumptions are very plausible in many cases, but they are usually difficult to prove, because these assumed happenings took place so far back in the history of the earth. Extensive studies have been made in our times about animals living in regions far away from their original habitats. Some of these animals have been intentionally transplanted by man and some have been brought in unintentionally on commercial carriers, as on ships, for instance. One of the very best and most recent examples of this is the presence of the Chinese mitten crab in the North Sea and in the Baltic countries following the opening of extensive shipping between Germany and eastern Asia. This mitten crab was almost unnoticed for years but during the latter part of the past decade has increased enormously and has developed suddenly into a serious danger to the fishing industry. The necessity of effectively fighting these obstructive crabs has led to thorough scientific investigations into all their characteristics and everything about them. The lively maritime traffic between Germany and eastern Asia will continue to leave many ways open for the further distribution of this resistant and adaptable crustacean, and a short account of its introduction into Europe, its distribution over Germany and neighboring countries, and its characteristics and ways and habits may be of general interest.

THE MITTEN CRAB'S ORIGINAL HABITAT

The genus *Eriocheir* is a native of eastern Asia and contains three species. The Japanese mitten crab (*Eriocheir japonicus* de Haan) inhabits the Japanese islands from Formosa in the south to the southern point of Sakhalin in the north, also the coast of the Asiatic

mainland across from Japan, the eastern coast of Korea, the coast northward to Vladivostok and perhaps even a little farther north. In Japan it goes far up into the mountains, and in these mountainous regions it is called the mountain crab.

The Chinese mitten crab (*Eriocheir sinensis* H. Milne-Edwards)

FIGURE 1.—Distribution of genus *Eriocheir* in East Asia; *horizontal lines;* region of habitat of the Japanese mitten crab; *vertical lines:* region of the Chinese mitten crab; *dotted region:* habitat of *Eriocheir leptognathus* Rathbun.

(pl. I) inhabits China from the province of Fokien in the south to the west coast of the Korean Peninsula (by the Yellow Sea) in the north. Its principal habitat is, however, north of Shanghai. Even though it is found far inland, it nevertheless seems to prefer regions near the coast. Kobayashi says that in Korea it always settles in the rice-

fields near the coast and that farther inland it lives only in the rivers. The species of *Eriocheir leptognathus* described by Dr. Mary J. Rathbun inhabits China from the province of Fokin in the south, where it is very rare, to the Liaotung peninsula on the Yellow Sea in the north. Its principal habitat is north of Shanghai (fig. 1).

The mitten crab belongs to the Grapsoid family group which is phylogenetically the newest group of the brachyuran crustaceans. The Grapsoid crabs are animals of the Tropics, but a few forms reach into the Temperate Zone, and the mitten crab is one of them. Thus it happens that we see characteristics in an animal living in the Temperate Zone which really belong only to animals living in the Topics. The Grapsoid crabs are marine animals, and it is an outstrnding characteristic of all marine crabs that larvae escape from thear eggs to drift free and pass through various stages before settling ion the bottom. Thereby they differ fundamentally from all real fresh-water crabs which do not go through these stages when the larvae drift. about free. A whole group of Grapsoid crabs spend their adolescence in brackish or fresh water where they find especially rich feeding However, that is the only time they do live in brackish or fresh water. They must always breed in the ocean. The larvae escape from the egg in the ocean and pass through the free-drifting larval stages in salt or brackish water, but however far they may venture into fresh water they must always return to the ocean for reproduction. The Grapsoid crabs, therefore, prefer regions close to the coast when they seek fresh water. Our mitten crab belongs to this group.

HOW THE MITTEN CRAB WAS BROUGHT INTO GERMANY

The mitten crabs live in the Temperate Zone in eastern Asia up into the far north. This fact has made possible their transfer to temperate Central Europe and to cold-temperate northern Europe. Their presence in Germany was probably made possible because of their reproduction through free-drifting larvae brought to Germany on commercial vessels. When the ships happened to fill their ballast water tanks in central or north Chinese ports during the larvae's spawning time, the 1.7- to 5-mm larvae of the mitten crab would, of course, get into the tanks, and again when the tanks were emptied in the German port the young mitten crabs, a few millimeters long, into which the larvae had developed during the trip, would, of course, get into one of the German rivers emptying into the North Sea. This could go on unnoticed year after year. They were undoubtedly brought in long ago. The first Chinese mitten crab, a large male, was discovered in the Aller, a tributary to the Weser, in 1912. One can thus consider that these crabs were first brought in during the first decade of this century, and their entry therefore coincides to a certain extent

with the establishment of intensive maritime traffic with eastern Asia. A specimen was first brought to me for identification in 1923 and a decade and a half or perhaps two may well have passed after they had first been introduced before we became fully aware of this new inhabitant in German waters.

It must seem astonishing that the mitten crab has increased within a period of perhaps three and a half decades in the German rivers in such an alarming degree. This tremendous increase was undoubtedly aided by the fact that they were not brought in fully grown but in large numbers as larvae or when very young. However, this enormous increase in such a short time was above all aided by the particular conditions in the German rivers.

The German rivers ceased long ago to be just rivers and became waterways, navigation highways, and traffic arteries. This change of the German rivers has made existence impossible for many native animals, as, for instance, for the predatory fishes which would have been of the greatest importance in fighting and checking these mitten crabs. Conditions were thus created under which this extraordinarily resistant mitten crab has been able to establish itself.

THE DISTRIBUTION OF THE MITTEN CRAB IN GERMANY

Although the mitten crab was found first in the Weser River system (in Aller near Rethem in 1912), it has not been seen there since. By later questioning Elbe fishermen, it was found that the crabs had appeared as a by-catch in the flounder fisheries by the mouth of the Elbe since about 1915. They seem hardly to have left the lower tide-water region after that. They were first seen in the upper tide-water regions above Hamburg in 1926, and by 1927 they were there in great masses. A few years later they flooded the waters of the mid Elbe (Havel, Province of Brandenburg) to such an extent that it became necessary to take measures to check them. By 1930 the lower sections of the Weser, as well as the lower and mid sections of the Elbe, were thickly infested with these crabs. In the late twenties they began to spread westward into the Ems and eastward into the Oder. They found their way westward from the Weser into the Ems through the many streams and canals in northern Oldenburg and eastward into the Oder through the waterways leading from the Elbe through Brandenburg. And with the beginning of this decade they commenced to spread westward from the Ems into northern Holland and through the Midland Canal and the Rhine into southern Holland, northern Belgium, and northern France. They have gradually established a particular breeding ground in the region of the Danish Great and Lesser Belt in the Baltic. Mitten crabs that had reached the Oder from the Elbe through Brandenburg, have with all certainty helped to establish these breeding grounds inasmuch as, upon reaching

maturity, they naturally moved on downstream into the Baltic in their hunt for salt water. And they may have come through the North Sea—Baltic Canal (Kiel Canal) as well. They have spread from these breeding grounds in the Great and Lesser Belt in the Baltic to Denmark, southeastern Sweden, East Prussia, southern Finland, and in some instances, to some of the adjoining countries on the Baltic. Today, according to Dr. Peters, lower and mid Elve as far as into Saxony, the Weser below Bremen, and the coast regions of Germany and Holland from the Elbe to the Rhine are thickly infested with them. In other sections they are only sparse (fig. 2).

FIGURE 2.—Distribution of the Chinese mitten crab; *horizontal lines:* now inhabited region; *dotted region:* very heavily inhabited.

REPRODUCTION

The mitten crab is, during its whole life, practically a fresh-water animal and is found hundreds of kilometers upstream in thickly infested rivers. With the development of the sex instinct, the urge for the sea also awakens in them, and in August, or after, they leave their feeding grounds, often located far inland, to move on downstream to the sea. The sex organs develop during this migration and the crabs reach puberty on the last lap of the journey through the usually brackish water in the tidal regions. In the fall they always gather to breed in large swarms in the brackish water in the lower course of the rivers.

The males come first and remain through the whole winter while the females come later, mate, and start immediately afterward to move on down to the sea. The eggs are laid within 24 hours after mating and are fastened to the small hairs on the pleopods on the underside of the abdomen with a cementlike substance which hardens in salt water. This cementlike substance hardens only in water that has a salt content of more than 2.5 percent, according to F. Buhk. The females, burdened with the weight of the eggs on the pleopods under their abdomens, choose to stay on in the deep water outside the river mouths through the winter. As soon as it gets warm in the spring, the tiny larvae escape from the eggs to start to drift about free (pl. 2). In all probability the females hunt up particularly brackish water for this purpose. In June or July, after all the larvae have left the eggs, both males and females set out for the river banks at the mouths of the rivers, where they gradually perish.

The intermittent stay in fresh water, and these long journeys far inland between birth and death, which both take place in salt water, bring about the peculiar character of the life cycle of these mitten crabs. They cannot repeat these long journeys to reproduce every year or two, which other crawfishes do, because the distances are too great. Breeding has, therefore, been put off to the last part of their life span. But under normal circumstances this single breeding period is compensated by an enormous egg production. The crabs, males and females alike, are therefore completely exhausted and worn out after mating, and waste away gradually. It is a sign of their generally fading strength that they are so covered with barnacles (Balanidae) (pl. 3) in the summer during their stay in the North Sea shallows, that they hardly move about at all; indeed they often cannot move even their mouth parts. They lack the strength to shed their shells which would enable them to get rid of these cumbersome barnacles.

Whereas the eggs need pure salt water to mature, the larvae leave the eggs in very brackish water. The prezoea, a free-drifting larva, leaves the egg and develops immediately into a 1.7-mm zoea (pl. 2, *a*). Subsequently, three additional larval stages follow. These larvae probably move gradually into less brackish water. The last zoea develops into the final larval stage, the 3–4-mm-long megalopa (pl. 2, *b*). The change from the free-drifting life of the zoea, with long suspended thorns and a rudderlike tail, to the more uneventful life of the crab on the bottom takes place in the megalopa. The megalopa are brought into fresh water with high tide and develop there into tiny mitten crabs, 2.5 to 3 mm long, the first stage of bottom life (pl. 2, *c*).

This migration from salt to fresh water in the larval stage and from fresh to salt water as adults toward the end of their life, is a distinguishing habit of the mitten crab, and, when considered biologically, the mitten crab appears to be in the act of becoming a fresh-water

animal. This transition demands important readjustment in their (body) system. Their life substance has the same salt concentration as sea water and therefore differs greatly from that of fresh water. Whereas animals in sea water, with equal salt concentration inside as outside the body, are not imperiled through any osmotic action, life in fresh water demands equalization, and the constant absorption of water by osmotic action through unprotected places in the body, as for instance through the gills, is retroacted by increased water outlet through the kidneys. Otherwise the plasma would be destroyed through continuous swelling. The migration of the tender mitten crab larvae from the sea into fresh water with its added requirement for body functions, therefore, implies strong intrinsic power.

THE BREEDING PERIOD

Although the time of mating and the laying of eggs is fairly fixed, beginning about the end of October and lasting until January, the larvae's hatching time changes very much depending upon the weather. When springs are warm, which does not happen often, at least not in northwestern Germany, the larvae hatch sometime between the end of March and May or June. But the time for hatching usually comes considerably later and lasts until far into July. Thus their whole development is, of course, delayed. During warm springs, the megalopae may appear in July or August in the fresh water below Hamburg, and there develop into the first bottom stage, but during unfavorable weather their appearance is delayed until October. In 1933, when it was exceptionally warm, the young mitten crabs reached an average length of 10 mm in October but again in 1935 and 1936, when the weather was unfavorable, their average size was only 4 to 7 mm when they went into winter rest.

THE WANDERINGS OF THE MITTEN CRAB

The migration of the larvae into the fresh water in the upper tidal regions is (probably) aided by the tidal currents. These feeding grounds are very rich, and the wanderings could have continued to end here, as they did up to the beginning of the twenties, if the number of the crabs had not increased so tremendously. It was this enormous increase that forced them to move on farther upstream in their search for food. But the crabs are too small at first to be able to make their way upstream against the strong current. During their first summer in their larval stage they are brought with the tidal current into fresh water, and during their second summer they stay there in the coast regions where the water recedes at ebb tide until they grow sufficiently to enable them to wander on.

In the late fall the crabs return in large masses to deep water for winter rest, causing such crowding in the narrow river-channels that the young ones, then in their second year, are not strong enough to fight for a place for winter rest there and are, therefore, forced to move on.

Consequently, as the catches by the dam in the Weser by Bremen show, the young animals begin to move on upstream in the beginning of winter but only sparsely during the cold weather in January and February. As soon as it gets a little warmer in March, these crabs, not yet 2 years old, commence to migrate upstream in such huge masses that more than 30,000 of them are caught and destroyed daily in Bremen in traps specially constructed for this purpose. The congestion is lifted when the crabs again swarm out into the shallow regions with the advent of warmer weather in the beginning of May.

These swarms, which once migrated from the tidal regions, are now

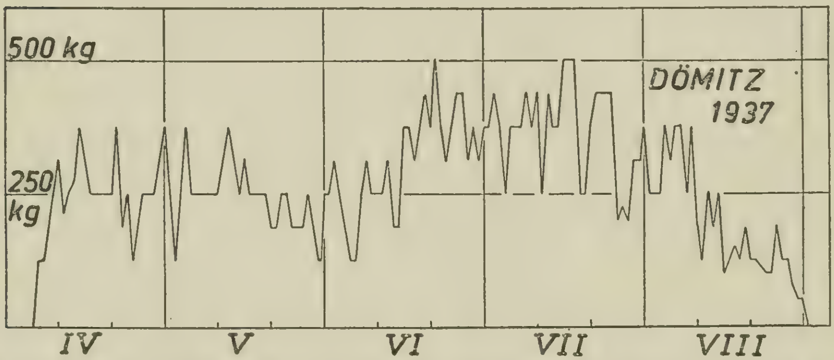


FIGURE 3.—Catch of mitten crabs at Doemitz, Germany, during April, May, June, July, and August, 1937.

forced to wander farther on because rivers that have been converted into navigation arteries do not hold sufficient nutriment for them. It is a wandering without a goal. Wherever a canal, or a rivulet, empties into the river some of the crabs always leave the large swarms to move into it. But in the Elbe, from Hamburg on, they have very few opportunities to branch off into suitable feeding grounds. The crabs heading upstream are, therefore, forced to remain for a long time in huge swarms. Only the Elde near Doemitz (in Mecklenburg), the Havel and the Saole can accommodate these swarms and consequently receive heavy visitations of the crabs. In these three rivers the migration begins in April about the time when it already has reached or passed its height in the tidal region, and continues into August. In Doemitz (in Mecklenburg) 44,400 kg of mitten crabs moving upstream were caught in specially constructed traps by the dam in the Elde rivulet in 1936, and 34,925 kg in 1937. As the curve (fig. 3) shows, the migration and the catch commence suddenly in

April and decrease temporarily during the end of May and early June, probably as a result of a shedding which takes place about this time. The migration is at its height in June and July and falls off during August. The swarms that penetrate into the Havel are even larger. About 100,000 kg of crabs were caught there in similar traps in 1936 (pl. 4, fig. 1). And even as far up in the Saole as Calbe 42,500 kg were caught in 1936. The migration decreases considerably higher up in the Elbe beyond the mouth of the Saole, inasmuch as the greater mass has branched off into suitable feeding grounds. In single instances only do they penetrate as far as through Saxony into Czechoslovakia. The mitten crabs, as we see, indeed, accomplish extraordinary wandering feats. The distance which the tiny larvae travel from the sea up to the vicinity of Hamburg is about 100 km, the distance along the Elbe from Hamburg to Doemitz about 120 km, from Hamburg to Garz on the Havel 220 km, and from Hamburg to Calbe on the Saole 350 km.

I have ascertained through marking tests the rate of speed at which the young crabs travel upstream against the current and in doing this I have marked the backs of 13,000 mitten crabs with good ship's paint of different colors during series of experiments in the Weser, the Elbe, the Havel, and the Saole. The crabs were placed in lots of 1,000 specimens at certain distances apart below the traps and the time was noted when the marked crabs again landed in the traps from which they had been taken previously. The evolution of these 13 experiments showed that the small animals, migrating from the tidal region in the lower course of the Weser, traveled a distance of 1 to 1.5 km daily and that the larger ones, moving against the current in mid Elbe, a distance of 2 to 3 km daily. In their upstream migration, they reach the Havel during the first summer and the Saole during the second summer.

When the mitten crabs have reached their full growth in the interior of Germany, they leave and wander back to the sea to reproduce. A shedding of the shell precedes this downstream migration so the crabs start out with thin, light shells and subtle elastic synovial membranes. The migration commences everywhere simultaneously in August and is in all certainty induced by incipient growth of the sex glands, inasmuch as the sex organs begin to develop in these migrating crabs during their wandering through mid Elbe. The migration downstream decreases slowly in mid Elbe during October after its height in September, whereas the migration continues in its lower course into November. The rate of speed at which these crabs travel has also been ascertained through experiments with color markings (pl. 4, fig. 2). In the course of four experiments, 1,600 crabs were marked and set adrift in the Havel and the Weser. Of the crabs which were captured, the three which traveled the longest dis-

tances had the highest average: (1) Total distance 338 km, time 29 days, or 12 km per day. (2) Total distance 257 km, time 43 days, or 8 km per day. (3) Total distance 368 km, time 38 days, or 10 km per day. These large crabs in the spawning swarm consequently travel downstream at the considerable rate of speed of 8 to 12 km per day and thus can reach the breeding places in the brackish water in 2 to 3 months even from the more remote regions.

It is not surprising that the young animals cease their slow wandering upstream in midsummer when the old animals commence their rapid downstream migration, because the young animals are forced to leave the channel in midstream when the two swarms meet.

SHEDDING OF THE SHELL, GROWTH, AND LIFE SPAN

The vertebrates, with their inner skeletons covered with a network of living cells, grow evenly and inconspicuously, but arthropods, with their dead outer armor, grow by leaps. The chitinous armor reinforced by deposits of lime must from time to time be thrown off and renewed because it ages quickly, breaks and becomes useless. Besides, growth is possible only by shedding the shell because the dead outer shell cannot be enlarged through growth as do the bones of the vertebrates. It must, therefore, from time to time be thrown off and replaced with a new and larger one. Preparation for the shedding of the armor is made in the forming of a new, thin, elastic shell under the old one. The blood pressure now increases through the absorption of water. The old armor bursts in the rear end between the carapace and the abdomen, the crab glides out backward and expands at the same time. The blood pressure produced to burst the old and expand the new shell is so great that the crab after shedding can move on its elastic legs without caving in. The new shell hardens through absorption of calcareous deposits. This peculiar periodic mode of growth with the shedding of the shell restricts the mitten crab to a comparatively slow growth. In growth through sudden expansion, limits are set to the elasticity, inasmuch as overexpansion would tear many organs. According to investigations made by Dr. Schubert, the length added by shedding is 24 percent in the smallest animals but decreases as they increase in size and is only 11 percent in the largest crabs, which are more than 70 mm long. The number of sheddings per year are limited and evidently strictly regulated. The gullet, the stomach, and the rectum, which reaches almost to the stomach, are coated with chitin and are shed with the shell. They must consequently be empty at the time of shedding. The shedding, is, therefore, preceded by a period of fasting. The fasting continues until the jaws harden. According to Dr. Schubert, the mitten crabs shed 6 to 8 times during their first year, 4 to 5 times during their

second year, and 2 to 3 times during their third year. The older crabs shed only once a year.

As the hatching of the larvae is usually completed in July, I count the years of life of the mitten crabs as running from July to July. Thus, according to my investigations, the average length of the crabs is: the 1-year-olds about 13 mm; the 2-year-olds about 25 mm; the 3-year-olds about 36 to 38 mm. I estimate that the crabs about 56 mm long in the spawning swarms are 5 years old.

NUTRIMENT

In discussions on the evil of the mitten crabs the question has always been an important one as to whether they attack and eat fishes. It is easy to understand that every fisherman whose catch falls off in vicinities where there are mitten crabs vows that they are wanton destroyers of fishes. But the question is not so easily solved. Timid fishes lose out, to be sure, where there are mitten crabs, and the crabs do attack fishes that have been caught in nets, thus having lost freedom of movement. They are omnivorous and eat whatever they can get. That does not prove, however, that slow mitten crabs catch speedy fishes at liberty. We have, in fact, kept fishes and mitten crabs together for long periods in the same aquarium, a mitten crab and a perch occupying the same corner, the fish directly above the crab without being molested by it. Dr. H. Thiel has proved through examinations of contents of stomachs of mitten crabs that the largest portion of their food comes from the vegetable kingdom, but they must to some extent get their food from the animal kingdom as the lime that is necessary to harden the shell otherwise would be lacking. They eat worms, especially Tubifex, mussels and snails, inferior crustaceans, water insects, insect larvae, and even dead substance of organic origin. Remains of fishes were found only in 4 to 5 stomachs of 1,000 mitten crabs, and these came from a region with huge swarms of young fishes. It may have been the remains of cadavers of young fishes that had served the crabs as food.

VOLUNTARY MUTILATION AND REGENERATION

The mitten crabs, like all higher crustacea, are able to throw off their pincer and walking legs and grow new ones at the same time with their next new shell. This ability enables them often to save themselves when they are attacked. With lightning speed they discard the leg the attacker has seized and then rush off. At the base of all 10 legs, between two joints which have grown together, there is another joint with a very thin shell. Through certain muscular contraction whereby the adjoining leg serves as lever, the endangered leg is broken

off in this joint. The same thing happens in cases of injuries. The wound caused by the breaking off of the leg is immediately closed with a thin membrane already formed so that all loss of blood is avoided.

Shortly before the next shedding takes place, a bud grows through the scar where the leg was severed and in it is formed a regenerated leg folded in two (pl. 5). It straightens out in the next shedding but is at first somewhat smaller than the discarded limb and lacks always the characteristic pilroe, which makes the fishermen think that they here have an entirely different animal when they find a mitten crab with two regenerated pincers in their by-catch. This lack of pilroe on the regenerated limb is interpreted as a retrogression to an original hairless form, but proof to this effect is lacking (pl. 5).

How much of this self-mutilation is dependent on the ability to renew discarded limbs is realized by the fact that the crabs are very little inclined to self-mutilation when the time for the next shedding is still remote.

MITTEN CRAB BURROWS

It is known that many tropical crustaceans that live in tidal regions on the coast or in the river mouths dig burrows for themselves into which they retire during ebb tide. The mitten crabs do it also in the tidal regions of German rivers. We find their burrows in firm marsh bottoms everywhere on the banks of the Elbe tributaries and in canals which dry out in ebb tide. It is easy to recognize their low and wide entrances and not to confuse them with the round openings to the burrows of the water voles. The burrows are always dug to slant downward and filled with water, which makes it possible for the crabs to await here the return of the water with high tide. Where the burrows are numerous, the undermined shore finally caves in and thus the mitten crabs are the cause of considerable damage in many places (pl. 6).

DAMAGE CAUSED TO FISHING

Fishermen maintain that the mitten crab catches and eats fishes in open waters. However, this does not tally. The healthy fish is much too quick and the mitten crab much too slow for that. Fishermen maintain also that the crab destroys the spawn and the fry. This could hardly be the case either. But in other ways they do a lot of damage, as for instance when fishes like flounders are caught in place nets. When the net reaches the bottom the crabs crawl high up on the net, eating the defenseless fish and becoming entangled with their many legs in the fine net threads. In their attempts to escape they tangle up the nets and finally cut them into pieces with their jaws. To the loss in catch there is added the destruction of nets and the loss of time caused by the constantly necessary mending

of damaged nets. When mitten crabs are caught as a by-catch in dragnet fishing, not only is the fish injured and made useless for sale by rubbing against the crab's toothed armor, but the nets wear out much sooner and must be replaced more often. It is estimated that the resulting cost of nets is tripled in many regions. When mitten crabs come upon eel-basket pots, they swarm into them, attracted perhaps by the scent, and as a result the eels do not go in, or if they do, they are devoured. In central Germany large hoop nets with which to catch the eels heading for the sea are often laid out behind the sluice gate. The crabs migrating in the fall unfortunately take the same route and are consequently caught in these hoop nets. When, as happens in Havel, up to 500 kg of mitten crabs are caught in a single night in a hoop net, the chances for eel fishing are impossible. As eel fishing is the most important source of livelihood for the fishermen in many regions, it is very easy to understand that the fishermen demand that adequate steps be taken to ward off their peril.

MEANS OF CONTROL

It is true that some predatory fishes and some aquatic birds and waterfowl devour the mitten crabs, but this means of exterminating them is altogether ineffective because of the crabs' enormous and rapid increase. The possibility of preventing their reproduction by catching the breeding swarms in the river mouths has been discussed, but however logical the idea may seem, considerable difficulties stand in the way of carrying it out. But more favorable opportunities to control the crabs have presented themselves in the interior of Germany.

The mitten crabs travel on the bottom of the rivers, forcing their way upstream where the current is strongest, and pile up below any dam that temporarily stops them in their wandering. Advantage of this opportunity is taken by the Weser dams in Bremen. Barrels covered with wire netting or canvas are lowered with davits to the bottom of the Weser. The crabs, jammed in against the dam, crawl high up on the barrels, fall into them and are caught in this way. In 1935 from January to May, 12,166 kg of mitten crabs (3,444,680 specimens) were caught, the greatest amount at one time being 407 kg (113,960 specimens) on April 15, 1935. In 1936, 12,786 kg (2,941,100 specimens) were taken.

When crabs are jammed below a dam they try in many ways to get by the obstacle. They crawl up on the walls and finally out on the shore, so as to pass the dam by land. It was thus that it was first learned what enormous masses of mitten crabs infest the German rivers. During warm summer nights the shore region is black with crabs; one cannot take a step without treading on them. In places where a dam is close to a city, it happens occasionally that mitten

crabs land on city streets and finally even penetrate into houses. This happened in 1931 in Rathenow on the Havel, in 1936 in a suburb of Magdeburg, and in 1938 in Calbe on Saole. The habit of the mitten crabs to leave the river bed led to the main methods used in Germany to control them. Where the mitten crabs leave the river in their efforts to get by the obstructing dam by land, extensive shore regions below the dam are shut off by means of sheet iron and trenches dug in the ground in front of the metal into which the mitten crabs fall while wandering along on the sheet iron. Such a project has been laid out by the Elde rivulet in Doemitz and has already been described, and also in Garz on the Havel, where 77,100 kg of mitten crabs were caught in 1935 and 58,300 kg in 1936. In Gruetz on the Havel, 12 km above Garz, a conduit has been led along the upper border of the slanting walled riverbank, and into this conduit the climbing mitten crabs fall and are led by it to a large pit in which they collect without being able to escape. A slanting piece of sheet iron between the conduit and the river prevents the crabs from circumventing the traps. Although here only those crabs are caught which escape the traps in Garz through parallel river beds, nevertheless 11,250 kg of crabs were caught in 1935 and 32,400 kg in 1936 (pl. 4, fig. 1; pl. 7).

In Calbe on the Saole, the mitten crabs preferably climb up the rough slanting wall below the dam which affords these adept climbers sufficient grip. Here large wire baskets have been suspended against the wall and at some distance above them sheet iron has been laid. The climbing crabs slide down this sheet iron and fall into the basket from which they cannot escape. In 1936, 47,440 kg were caught in these baskets during the catching period from April to August (pl. 8).

No special traps need be laid to catch the old downstream-migrating animals. They always move with the strongest current and are therefore caught in front of the turbines and in the eel-basket pots behind the dam outlets. In this way 49,400 kg (about 227,000 specimens) were caught in 1935 in the Havel and 4,814 kg (about 34,470 specimens) in 1935, and 4,836 kg (about 27,560 specimens) in 1936 in Bremen.

These numbers do not by any means include all the mitten crabs caught. The young crabs migrating upstream, which pile up in front of the dam, are often caught there in large numbers in the eel-basket pots kept in front of the dam through the summer. Including these catches, the total catch of crabs moving up and downstream was 137,650 kg in the Havel in 1935 and 129,300 kg in 1936. In verified catches in Germany, altogether 262,600 kg were caught in 1936 and 190,400 kg in 1937.

UTILIZATION OF MITTEN CRABS

It is evident that efforts should be made to convert into profit these huge masses of mitten crabs caught daily during the main migration period. In Bremen the crabs are boiled and distributed to farmers who feed them to pigs with good success. Many fishermen crush their by-catch of mitten crabs and feed them raw to ducks which understand very well how to pick out the soft substance and thrive well on it. In Garz and Gruetz on the Havel, the mitten crabs are ground in large mills, and when this mutage cannot be fed to ducks, it is dumped into the rivers where the young fishes eat it eagerly. This is, of course, unprofitable and consequently experiments have been made for a long time by the "Havel," an association for the protection of fisheries in Gruetz, which would lead to utilization of the mitten crabs. These experiments have yet not been concluded and, therefore, can not be reported on.

MUTATION OF MITTEN CRABS

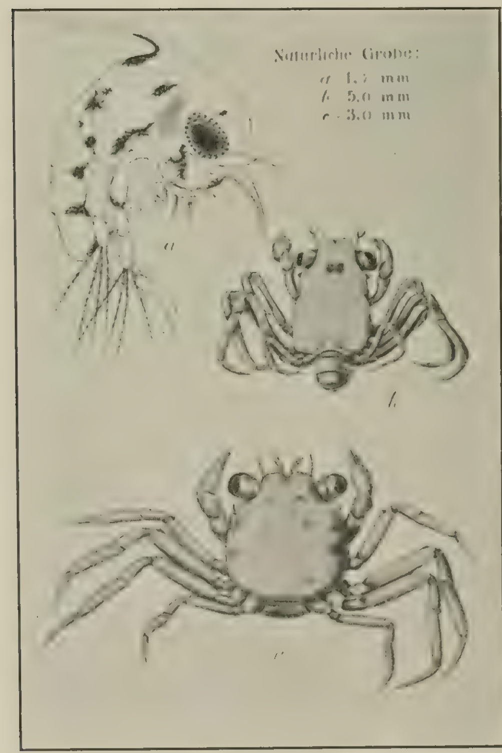
The mitten crabs have reacted to their introduction into a strange environment with some very conspicuous changes in their outward form. Plate 9 shows the three best examples of this change in the form. The changes have taken place principally in two systematically important characters—the rostrum teeth between the eyes and the three pairs of protuberances on the back behind the forehead.

If one assumes that the mitten crabs were introduced into Germany around the turn of the century, it has required a comparatively long exposure to the new environment for these mutations to take place. No traces of changes were noticed in specimens brought to us in the twenties. In 1932 and 1933 the mitten crab was conspicuously labile in systematically important characters. The rostrum teeth were weaker and seldom pointed but mostly blunt, almost round; the indentures between the teeth were flatter and often shaped very irregularly; the protuberances on the back were fainter and those of both rear pairs seemed to be inclined to fuse. At that time it was barely possible out of a large mass of mitten crabs to find even a few typical specimens to be used as exhibits. Now the mitten crab again has its original form without any deviation from the Chinese specimens brought to me only recently from Shanghai. It seems (more cannot be said) that the original mutation was accompanied by a general fluctuation of those characters which were affected by the change.

The parts of the foregoing report not based on my original investigations are taken from volume 47 of the Reports of the Hamburg Zoological Museum and Institute (works by Drs. Peters, Thiel, Schubert, Hoppe, and Peters), which I recommend for further information.

Chinese mitten crab, male: *above*, back; *below*, belly.

1. Female with eggs.

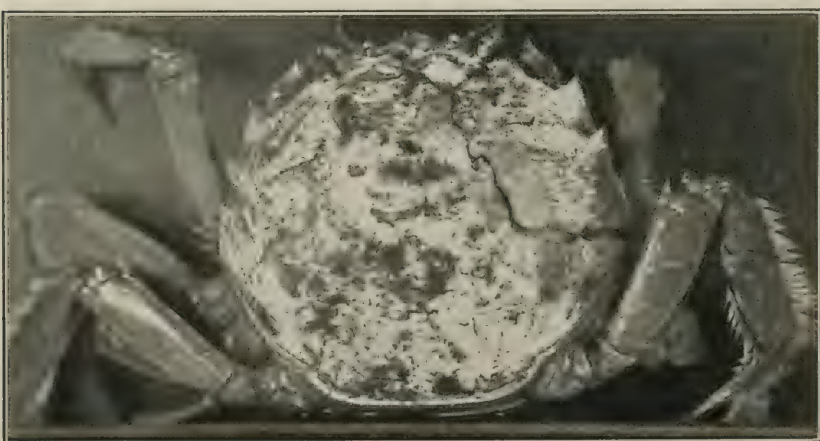


2. The larvae: *a*, zoea; *b*, megalopa; *c*, in first bottom stage.

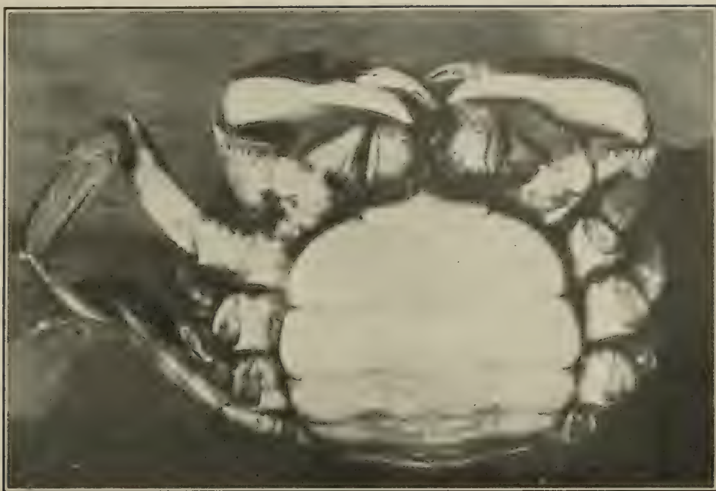
REPRODUCTION.

DYING OLD FEMALE DENSELY COVERED WITH BARNACLES.
Above, back; *below*, belly; the whole mouth organs densely covered with barnacles and scarcely movable.

1. Catching young mitten crabs wandering upstream into traps by the Havel dam in Gruetz (in Brandenburg) during the summer of 1936. (Photograph by Weltbild.)



2. This large animal marked with white paint was turned loose in Garz on the Havel, recaptured near Wittenberg on the Elbe; it traveled 123 km. in 12 days.



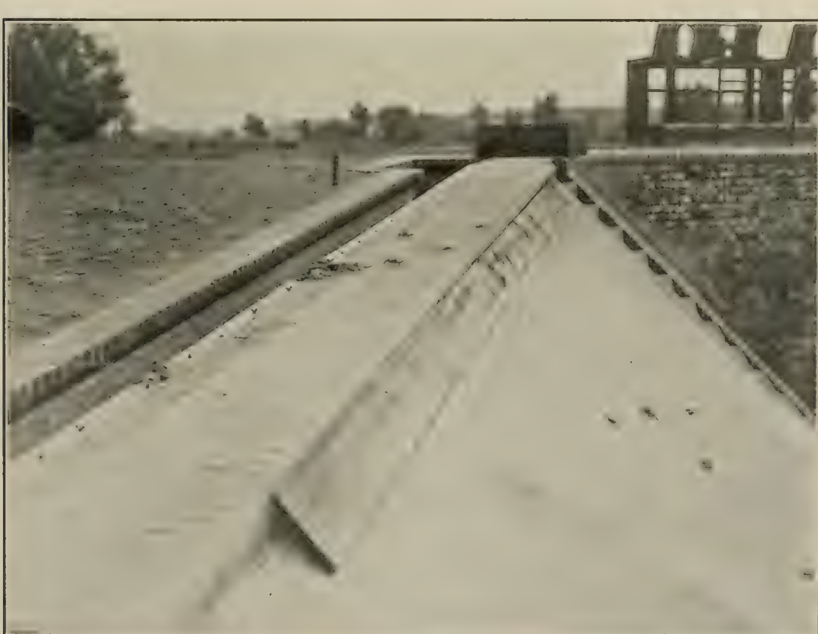
1. Female belly; on the *left side* (right side on the picture), regeneration buds on the stumps of first, second, and third walking legs; on *right side* (left side on the picture), regenerating buds on the stumps of second and third walking legs.

2. Male belly, with newly formed left pincer (right pincer in picture), without hairs, pile.

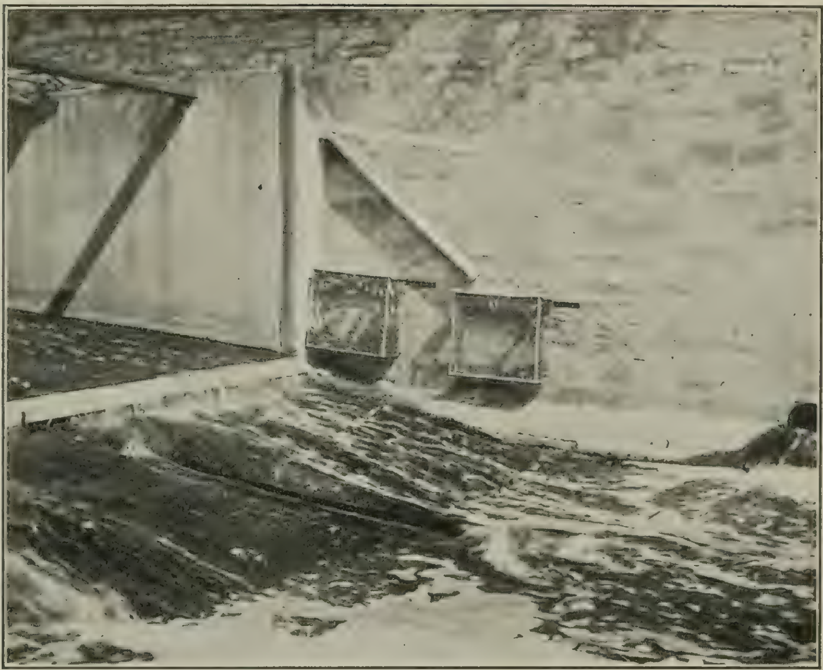
REGENERATION.

RIVER BEDS AT LOW EBB TIDE WITH MITTEN CRAB BURROWS.
Above, the broad, flat entrances to the burrows; *below*, the undermined bank falls in.

1. The dam in Gruetz on the Havel seen from below; on the right side on the picture the needleweir and on the left side the rampart. Left from it the sloping wall and on its upper edge the trap. (Photographs by Dr. Roehler.)



2. Trap projects by the dam in Gruetz on the Havel left wall with trench traps and climbing mitten crabs. (Photographs by Dr. Roehler.)



TRAP BASKETS.

Above, by the dam in Calbe on the Saale; *below*, on the Elbe bridge in Magdeburg. (Photographs by Dr. Kisker.) From Kisker Fischereizeitung, vol. 37, fig. page 510, 1934.

THREE MUTATIONS OF THE MITTEN CRAB FROM THE ELBE.

THE BIOLOGY OF LIGHT PRODUCTION IN ARTHROPODS [1]

By N. S. Rustum Maluf
The Osborn Zoological Laboratory, Yale University

* * * *all the fire emitted by wood and other combustibles when burning, existed in them before in a solid state, being only discovered when separating—*

—Benjamin Franklin

Luminescence, in contrast to *incandescence*, is the emission of light as a result of some other factor than heat. There are various types of luminescence: (1) *Thermoluminescence* is the emission of light at abnormally high temperatures but nevertheless at temperatures well below 525° C. It resembles phosphorescence in that it is dependent on previous irradiation, e. g., fluorite will cease to emit light at 100° C. if kept in the dark for a long time. Since not all phosphorescent substances are thermoluminescent, thermoluminescence is probably not merely a case of phosphorescence intensified by heat. (2) *Phosphorescence* and *fluorescence* are the emission of light as the result of an absorption of radiant energy. In fluorescence the emission (generally of a longer wave length than the incident light) occurs only during the time of irradiation. Harvey (1919) has pointed out, however, that the distinction between fluorescence and phosphorescence is probably only arbitrary since some substances will yield light for only 1/5,000 of a second after irradiation and since some substances, which fluoresce at ordinary temperatures, will phosphoresce at low temperatures. Chitin, eosin, and most proteins will fluoresce in ultraviolet light so that an excursion of a human being into an imaginary world in which there is no incident visible light but in which there is ultraviolet irradiation would not mean that all would be darkness. He would be able to see living organisms and various minerals. (3) *Triboluminescence* results from the shaking or rubbing of certain crystals, e. g., uranium nitrate, sucrose. (4) *Crystalloluminescence* is observable when certain substances in solution are crystallizing out, e. g., AsO, NaF. All such substances are triboluminescent but the converse is not true. It has been shown that crystalloluminescence is not necessarily due to friction. (5) *Chemiluminescence*, in contrast to the above types of luminescence, is an oxidation and generally, if not always, requires oxygen or ozone. It thus includes the lumines-

[1] Reprinted by permission from Science Progress, vol. 32, No. 126, October 1937, with extensive revisions and additions by the author.

cence of organisms (*bioluminescence*). Examples of chemiluminescence in the inorganic world are numerous. Thus, freshly cut Na or K metals form an oxid film accompanied by the emission of light, which is perceptible in a dark room.

A. DISTRIBUTION AND STRUCTURE OF THE LIGHT-PRODUCING ORGANS

For a treatment of the earlier literature bearing upon this topic, de Kerville (1890), Mangold (1910–14), Harvey (1919), and Pratje (1923) should be consulted. Dahlgren (1915, 1916) has given a semipopular and well-illustrated account of the distribution of light organs in marine invertebrates. It is of interest to note that no truly fresh-water animal has as yet been determined, for certain, to possess a light-producing organ.

1. Crustacea.—Light-producing organs have been found among the Ostracoda, Copepoda, Schizopoda, and Decapoda. Luminescence in the ostracod, *Cypridina hilgendorfii*, the principal subject of the Harveiian school is extracellular. The luminescent organ in this animal is composed of maxillary gland cells, each cell opening by a separate pore with a valve (cf. also Kanda, 1920, and the work of Doflein and of Müller, quoted in the above works). Upon the contraction of certain muscles, the secretion is forced to the exterior from the saclike reservoir and luminesces in the sea water. In the deep-sea shrimp, *Acanthephyra debelis*, the light-organs are scattered over the surface of the body. The shrimp, *Systellaspis*, possesses a large luminous gland which secretes a luminous material into the sea water (Harvey, 1931*a*). This species occurs at depths between 600 and 800 fathoms off the coast of Bermuda. Luminescence at abysmal depths may be useful for illumination, although Kemp (1910) has noted that the vast majority of marine animals possessing photophores (including decapod Crustacea) live at the surface or at intermediate depths and never occur at the bottom, at least in deep water.

2. Chilopoda (*centipedes*).—No millipede has as yet been established to be self-luminous. The centipede, *Scolioplanes crassipes* (cf. Koch, 1927), emits a vivid green light from its sterna. When it crawls, it leaves behind it a trail of luminous fluid droplets which emit green light. This shows that both the luciferin and luciferase are secreted to the exterior. This would require a perforation at some point in the membrane of each secreting cell, since luciferase is a complex protein (see below). Each light organ of this animal is a large hypodermal cell. A similar condition exists in *Geophilus linearis* and other members of the order Geophilidae of the class Chilopoda (centipedes).

Sudden submersion in water, weak induction currents, chloroform, or a rise in temperature of about 10° C. stimulates the production of light in *Scolioplanes*.

The organs are equally developed in both sexes and luminesce all the year round and not only, as some have believed, during the breeding season (Cook, 1900). The fact that all the Geophilidae are eyeless also indicates that luminescence in these forms does not serve for sex attraction. Light production may, however, conceivably be significant in repelling enemies or in attracting prey.

It is of phylogenetic interest to note that the luminosity of certain "terrestrial" oligochaete annelids (Walter, 1909) is produced by the secretion of hypodermal glands.

3. Hexapoda.—Luminous insects are nearly restricted to two families of the Coleoptera: (1) The Elateridae or "fireflies," [3] have many luminous species all of which belong to the nonarid tropics or subtropics and all of which are members of the genus *Pyrophorus.* (2) The Lampyridae or "glow-worms," contain several hundred known luminous species, included in several genera, most of which occur in America, the West Indies, and the Malay Archipelago. In many species both sexes may be about equally luminous while in others the intensity of light production may predominate either in the female or in the male but more usually in the latter.

The luminous organ of at least a number of Lampyridae probably arises from the same embryonic fundament as the fat-body (cf. Williams, 1916–17, and Okada, 1935) and lies above the sixth and seventh abdominal sterna. It consists of (1) a dorsal layer of reflector cells which are white in appearance owing to the presence of crystals of xanthin, uric acid, or both; (2) a ventral mass of large cells (the light-producing cells) containing photogenic granules (not fat granules); (3) large tracheal trunks and tracheoles; (4) nerve fibers; (5) nonpigmented and somewhat translucent sternal plates beneath the light-producing cells. *Pyrophorus* (an elaterid) has a pair of light-organs at the lateral tergal margins of the prothorax and also a single light-organ on the ventral anterior median region of the abdomen.

In the larva of the tipulid fly, *Bolitophila luminosa* (Wheeler and Williams, 1915), part of each Malpighian tubule is photogenic. This is an interesting modification when one realizes that the essential feature of the reflector layer is insoluble purine crystals. Insects with luminescent organs also occur among the Collembola (*Lipura*, *Amphorura*, *Neanura*), the Neuroptera (*Teleganoides*, *Coenis*), and the Diptera (*Bolitophila* and *Ceroplatus* larvae). Certain Collembola (Heidt, 1936) secrete a luminous fluid to the exterior, the luminescence of which was shown not to be due to bacteria.

The interior of certain "firefly" eggs (*Pyrophorus* and various lampyrids) luminesces even prior to any embryonic differentiation. Dubois (1885) observed this to be the cause of error of some observers

[3] A "firefly" is any luminous beetle capable of flight, elaterid or lampyrid. A "glow-worm" is any practically wingless luminous beetle, larva, or adult.

who had stated that light is given off by the whole body of the adult. This statement of certain observers had already been refuted by some of Dubois' predecessors who, Dubois considered, must have noted only males. In 1854 Carpenter affirmed that the egg of *Lampyris* emits light when within the ovary, that the freshly laid eggs are luminous, and that the light does not issue from luminous material adhering to the egg but from the egg itself. The eggs of the common North American lampyrids (*Photinus*, *Photuris*) are, on the other hand, nonluminous (Buck, personal communication).

The larval light-organ, which is not identical with that of the adult, persists and glows in the pupa and is absorbed only at the time the adult emerges. Now, certain prominent biologists (such as Kuhnt, 1907; Pierantoni, 1914 and 1918; Buchner, 1914 and 1926) have claimed that luminescence in insects is due to the presence of intracellular symbiotic bacteria. Dubois' (1914a) numerous attempts at bacterial cultures from such light organs were negative and Harvey and Hall (1929) banished this notion when they found that "the adult luminous organ developed perfectly from larvae having both light-organs removed." The luminous granules in the photogenic cells are, therefore, not due to microorganisms. Bacteria probably play a nil factor in the luminosity of practically all species of living extant Metazoa. Certain fishes, such as *Photoblepharon* and *Anomalops* (cf. Harvey, 1921 and 1925), form the established exception to this rule. It is of interest to note that only luminous bacteria, fungi, and a few fish produce light continuously and that, as noted by Harvey (1924), fishes which luminesce continuously have bacteria to luminesce for them. If, then, continuous luminescence is a criterion solely of luminous bacteria and fungi, it seems very probable that the above fishes are the only luminous Metazoa which do not themselves produce light but which harbor symbiotic(?) luminous bacteria.

STIMULATION TO LUMINESCENCE

As already explained, only luminous bacteria and fungi produce light continuously. Other forms emit light at intervals depending upon the periods of stimulation.

1. *Rhythmic synchronous flashing en masse.*—The phenomenon of the strictly synchronous flashing of fireflies en masse, frequently observed in the Tropics, has excited a considerable degree of interest and is the subject of an excellent review by Buck (1938). Hence the literature handled by Buck will not be dealt with here. Buck's plausible theory for the phenomenon will be treated at the end of this topic in connection with the significance of flashing in the economy of fireflies.

In the journal Asia for February 1924 is an article by Carveth Wells on his experiences in the Malay Archipelago (cf. Morse, 1924):

> The air was full of extraordinary fireflies. About every fifteen minutes these flies separated into two armies, one settling on the trees growing on the left bank of the river and the other on the right. Then, when I had decided that the fireflies had gone to bed for the night, the whole army on the left bank gave one big flash in perfect unison, which was immediately answered by one big flash on the right. How these flies managed to keep time absolutely beats me, but they did so, though there must have been thousands of them stretching along the river-banks for a hundred yards or more. The illumination was so strong that the branches of the trees could be seen quite distinctly.

This is only one exemplary case out of many. Several other animals exhibit rhythmic synchronous behavior of various types, e. g., the rhythmic synchronous chirping of certain crickets and locusts (Allard, 1918).

2. *Diurnal rhythm.*—Fireflies generally flash only at night, i. e., exhibit a 24-hour (diurnal) periodicity. In a paper read before the American Society of Zoologists, Buck (1935 and 1937) described his studies on the periodicity and diurnal rhythm in the firefly, *Photinus pyralis:*

> In nature, males of *P. pyralis* ordinarily flash every evening between 7 and 9 p. m. The time of flashing is correlated with temperature and light intensity. Males which have been in strong light long flash immediately if the intensity is sufficiently reduced, regardless of the time of the day, showing that the regular evening flashing period can be modified. Males kept continuously in darkness do not flash. If, however, they are exposed to weak light they flash (regardless of the time of the day) provided they have previously been in darkness 24, 48, 72, or 96 hours but not if they have been in darkness 12, 36, 60, or 84 hours. If males which have been in darkness less than 24 hours are exposed to weak light and left in it they do not flash until the sum of the time spent in darkness and the time spent in weak light is equal approximately to 24 hours. It is thus apparent that there exists in the firefly an inherent diurnal periodicity which is manifested by periods of flashing which recur at 24-hour intervals and which persist for at least four days in the uniform environment of the dark-room. It is also clear that, although in the field this periodicity coincides with the diurnal changes in light intensity, it is not actually linked to any specific hour of the day.

By "inherent" Buck does not mean "inherited" but implies that the 24-hour rhythm is produced by internal stimuli. A similar condition had been noted in female larvae and female adults of *Lampyris noctiluca* (Perkins, 1931). The animals exposed continuously to light stopped glowing about the third day, while those receiving diffuse light by day, and those in continued darkness continued to glow at normal hours (10 p. m. to 4 a. m.) for about 2 weeks.

It has been noted that when the eggs of the stick-insect, *Dixippus* (Schleip, 1914, 1920), are placed under constant light conditions the adults no longer exhibit any periodicity in the migration of hypodermal pigment granules. Similar experiments are necessary in order to determine whether the internal stimulus producing the periodical flashing in fireflies is inherited. The occurrence of diurnal rhythms in general is the subject of a recent review by Welsh (1938).

3. *Basis of the rhythmic flashing of fireflies.*—Since when the photogenic cells are exposed directly to the air or when the intact animal is placed in one atmosphere of approximately pure oxygen, luminescence is continuous, it is clear that the regulation of the flashing rhythm is a result of regulation of the oxygen supply.

Because destruction of the brain or severing of the nerve cord anterior to the photogenic organs causes an immediate cessation of light production (see also Peters, 1841; Macaire, 1822; Lund, 1911; Williams, 1916–17) and because electrical stimulation of the ventral nerve cord affects flashing (Heinemann, 1886; Perkins, 1931; Snell, 1931, 1932), the mechanism of oxygen regulation must be under nervous control—probably a result of spontaneous discharges from the brain. The presence of the brain is not necessary, however, if the ventral nerve cord is electrically stimulated (Snell, 1931, 1932).

Lund (1911) showed that the control of flashing is not exercised by a regulation of the blood flow (as was believed by Dubois, 1886) or of the muscular respiratory mechanism (as was believed by Heinemann, 1886, and Watasé, 1895). He noted that no movements of the skeleton, observable with a binocular, are synchronous with flashing.

It has been the general opinion in America, among those interested in the subject, that the nervous system exerts its control by acting on the tracheal end-cells, especially since Schultze (1865), Bongardt (1903), and Geipel (1915) sometimes observed fibers in contact with these cells. The realization that even the ordinary hypodermal cells of arthropods are generally richly supplied with a network of multipolar nerve cells (Schleip, 1914; cf. Hanström, 1928; Tonner, 1933) would tend to weaken any conclusions from the above evidence. Because the tracheal end-cell was sometimes stained darker than the tracheoles, Dahlgren (1917) suggested that there might be a contractile layer of cytoplasm around it. He then stated that "the large body of cytoplasm surrounding it sometimes shows a radial structure that may point to a contractile power." His figure which illustrates such a structure is, however, not convincing. As far as I know, no one else has observed any such intracellular radial structure. Furthermore, even if we did rest upon the hypothesis of a contractile mechanism, it is incomprehensible how such a mechanism could produce a rapid obliteration of oxygen diffusion into the photogenic cells since some gaseous oxygen would still be present in the proximal portions of the tracheoles and contraction of the end-cells would merely compress the gas farther into the tracheoles and deeper into the photogenic tissues. There seems to be nothing back of the tracheal end-cell theory and, actually, the concept of a contractile tracheal end-cell is in direct antithesis to facts that we know. Thus, if contraction of the end-cells obliterates the oxygen supply, why

should anaesthesia of the normal animal initially abolish luminescence? We would expect, on the contrary, the "contractile mechanism" to relax and thus admit oxygen. Also, why should stimulation of the ventral nerve cord of the decerebrate creature produce glowing? We would expect, on the contrary, the "contractile mechanism" to contract and thus impede the oxygen supply. The tracheal end-cells are not exclusive to the photogenic organs but are present at the tracheoles of all insects (cf. Deegener, 1928) and Bongardt (1903) has described tracheal end-cells in the light-organs of larvae of *Phosphaenus hemipterus*—an animal which displays no brisk flashing rhythm.

Now, von Wielowieski (1882), Emery (1884–86), Watasé (1895), Bongardt (1903), and Townshend (1904) had believed that the tracheoles entering the photogenic organs of Lampyridae terminate intercellularly. Von Wielowieski (1889) later considered that they end intracellularly. Williams' (1916–17) illustrations indicate intracellular penetration. Lund's (1911) observations bear out the latter viewpoint conclusively: "The fact that they do penetrate into the cytoplasm is clearly shown by the fact that cross-sections of the tracheoles appear close to the nuclei of the large photogenic cells in the same focal plane . . . " For other literature concerning the intracellular penetration of tracheoles in the tissues of insects in general, cf. Wigglesworth (1931).

Wigglesworth's (1929, 1930, 1931, 1932) direct observations on the motion of air and liquid into the tracheoles during activity and rest of the corresponding tissues should be well known and will, in time, become classical. His observations on translucent insects show that the tracheoles do not collapse when the fluid leaves them. His conclusion with respect to the phenomenon is that, during activity, due to elaboration of metabolites (e. g., lactic acid) of lower molecular weight than the precursors, the osmotic pressure in the blood and tissue fluids is raised, thus causing a withdrawal of liquid from the semipermeable tracheoles into the tissues. The writer (1938) presented cogent evidence that light-production is the result of a rise in the osmotic pressure of the photogenic cells consequent to a rise in their metabolic activity as a result of nervous stimulation. The rise in osmotic pressure must draw air into the tracheoles and thus causes light production. With the immediate oxidation and reconversion of the metabolites, the intracellular osmotic pressure must fall rapidly and, as a consequence and due to capillarity, the tracheoles will become filled with fluid once more and the photogenic cells will cease to produce light (fig. 1). The oxygen that would gradually diffuse into the photogenic cells through the column of fluid in the tracheoles is probably only just adequate for maintenance of the cells and would hence be consumed too rapidly to allow for

the minimal intracellular oxygen pressure necessary for appreciable luminescence.

4. *Decline in the intensity of a flash.*—Brown and King (1931) measured the intensity of the light produced by *Photuris pennsyl-*

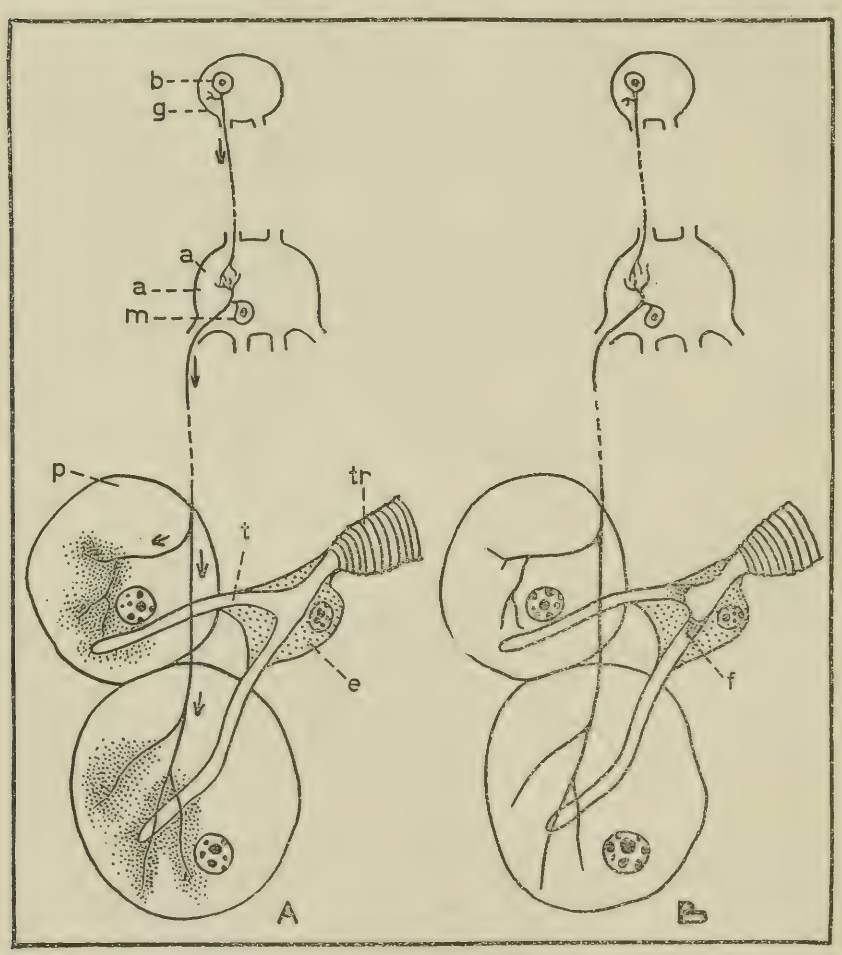


FIGURE 1.—Diagram illustrating the mechanism of the control of flashing in the "firefly."

A. A spontaneous discharge from ganglion cell, *g*, in the brain, *b*, is transmitted to the motor cell, *m*, in the terminal abdominal ganglion, *a*, and from thence, along the motor fiber, to photogenic cells, *p*. This excites these cells to activity, raising their osmotic pressure and thus withdrawing fluid from the tracheoles, *t*. This admits air, coming through the trachea, *tr*, into the interior of the cell. *e* is the end-cell found at the tracheoles of all insects.

B. Condition during inactivity of the specific cerebral ganglion cells, at which time the lactic acid is oxidized to water and CO_2, thus lowering the osmotic pressure in the photogenic cells. This allows the passage of fluid, *f*, into the tracheoles by capillary pressure and thus keeps air from directly penetrating the cells.

vanica as a result of a single electrical stimulus. A series of responses follows a single adequate stimulus with an increasing time interval between each response, until the responses, declining in intensity, eventually fade away (fig. 2). The decrease in light intensity following

a stimulus implies a decrease in the velocity of a reaction in the light-producing cells which, as Brown and King consider, can depend only on differences in the concentrations of luciferin, luciferase, or (and) oxygen. This consideration issues from the fact that we know a number of things: (1) Molecular oxygen is necessary for the luminescence—i. e., the process is an oxidation; (2) a substrate, luciferin, is oxidized through the agency of an enzyme classified among the aerobic oxidases and termed luciferase; (3) according to the phenomena of mass action, the velocity of a chemical reaction varies directly with the concentration (activity) of the reacting components. Owing to the fact that the luciferin-luciferase reaction shows a similar relationship in vitro, where the oxygen available is constant, to that depicted in figure 2, Brown and King concluded that the declining concentration of the luciferin-luciferase system was the determining factor in the "die-away" portion of the response. Because, however, of the much slower decline in luminosity in the in vitro conditions than in the intact animal and because of the facts stated in the following subsection, it seems probable that the decline in luminosity in the intact animal is due to a decrease in the concentration of oxygen in the vicinity of the photogenic cells.

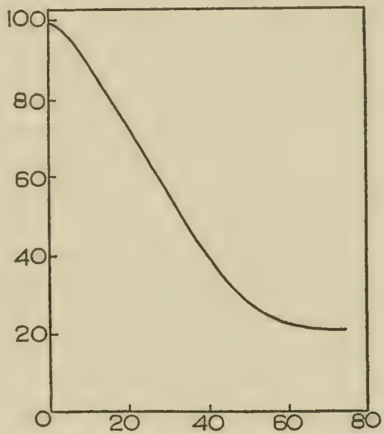


FIGURE 2.—The magnitude of the photogenic response of *Photuris pennsylvanica* initiated by a single electrical stimulus. Ordinate: intensity of the flash in terms of the initial (=100). Abscissa: time scale (10 units = 0.833 seconds). (After Brown and King.)

5. *Significance of luminescence in the economy of an animal.*—After reviewing the literature on the subject, Gazagnaire (1890) came to the conclusion that the intensity of luminescence in geophilid chilopods is intimately correlated with the time of sexual activity. Carpenter (1854) had already remarked that the same holds true for insects. The increase in the intensity of luminescence at such a time may be due to a raised rate of metabolism at this time; or, in the words of Carpenter, "the activity of this combustion is stimulated by anything which excites the vital functions of the individual." The notion, however, that luminescence has a secondary sexual function in chilopods cannot be upheld, since all the Geophilidae (the order which includes the luminous forms) are eyeless. In fireflies, on the other hand, the case is quite different. Thus, according to Mast (1912, 1923), "the female [firefly] in response to a flash of light produced by the male turns the ventral surface of her abdomen toward

him no matter where he may be located; and the male, in response to a flash of light produced by the female, turns and flies or walks directly toward her no matter where she may be located." (See also Osten-Sacken, 1861; and McDermott, 1912, 1917.)

It remained for Buck (1935, 1937a) to determine how the male distinguishes the flash of a female from that of another male. Thus, at nightfall the female firefly (*Photinus pyralis*) climbs up on the herbage and the male flies about, flashing at fairly regular intervals of about 5.8 seconds at 24° C. The female responds by flashing 2.1 seconds after the male flash. The length of the response interval also varies inversely with the temperature.

The male responds to flashes of artificial light and to flashes produced by other males if they occur about 2 seconds after his flash. This shows that no possible difference in the color, duration, or intensity of the light produced by the two sexes, or difference in the relative motion or form of the luminous area, is of any importance in enabling the male to distinguish between flashes emitted by male and female. The essential factor in the ability of the male to distinguish between flashes produced by the female and those produced by other males is the fact that the female invariably responds to the flash of the male at a nearly constant level of 2 seconds.

The synchronous flashing of masses of fireflies has been explained by an application of the above facts (Buck, 1935a, 1937c, 1938). Thus, other males may join in precise unison even though they had been flashing asynchronously originally. This involves a readjustment of the phase but not of the frequency. Similarly, other females in the vicinity may act accordingly—i. e., a single pair may cause a swarm of synchronous flashings. In other cases, however, swarms may exhibit no synchronism (e. g., *Photinus pallens*, a Jamaican firefly). Sheer photopositivity is the probable explanation for the huge swarm of *P. pallens*, since swarm-nuclei of this species may be artificially formed by flashlight. In such cases, mating "appears to be due entirely to accidental contact of the sexes during their peregrinations on the branches. The aggregation habit thus seems to take the place of the accurate systems of flashing signals which serve to bring male and female together . . ." (Buck, 1937c).

CHEMICAL PHENOMENA

1. *Luminescence an oxidative process.*—In 1667, Boyle, by means of a modified von Guericke (1634, 1672) air pump, discovered that air is necessary for the existence of animals and for the luminescence of bacteria (although, of course, he did not recognize the bacteria as such) and "glowworms" (*Lampyris* sp. larva or the wingless luminous adult English female). Following the discovery of oxygen by Lavoisier, Spallanzani (1796) was evidently the first to indicate that bioluminescence is an oxidative process. Murray (1826) showed that when oxy-

gen is replaced by irrespirable gases luminescence in *Lampyris* is abolished. "The phosphorescence," wrote Carpenter (1854) concerning luminescence in fireflies, "appears to be occasioned by the slow combustion of a peculiar organic compound, the production of which is dependent for its continuance upon the life and health of the animal; the activity of this combustion is stimulated by anything which excites the vital functions of the individual, and it is particularly influenced by the energy of the respiratory process. *If the opening of the trachea which supplies the luminous sac be closed, so as to check the access of air to its contents, the light ceases* [italics mine]; but if the sac be lifted from its place, without injuring the tracheae, the light is not interrupted. In all active movements of the body in which respiration is energetic, the light is proportionally increased in brilliancy. If the luminous segments be separated from the rest of the body, they continue phosphorescent for some time." The italicized observation shows that there is no effective ventilation of the air in the tracheae of the luminescent organ by other spiracles than those belonging to the light-producing segments (see also Heinemann, 1886; Hess, 1921; and Maluf, 1938). In fact, Lyonnet's early observations (confirmed by others, cf. Babák, 1921) show that ventilation is to a great extent segmentally localized even in tracheates with as well developed a tracheal system as caterpillars. Ofsianikof (1863) also found that the luminosity of *Lampyris noctiluca* ceases in vacuo but recommences on the readmission of a little air and becomes very dull in an atmosphere containing an excessive amount of carbon dioxid. Temporary immersion in glycerin also caused a cessation of luminescence possibly due to a plugging of the spiracles. The condition was quite reversible, however, upon washing with water, in which glycerin is soluble. That oxygen is actually used up in the photogenic process itself and that the absence of luminescence in the absence of oxygen is not merely due to a general interference with the cellular functions was first shown by Dubois who found that luminous extracts of arthropods and the mollusk, *Pholas*, will not emit light in the absence of oxygen but will do so upon the readmission of oxygen. These findings have been confirmed by Kastle and McDermott (1910), Harvey (1916a, 1917b, 1920), and others.

Contrary results were presented by Kanda (1920, 1920a), who noted that the intensity of light produced by an aqueous suspension of luciferin-luciferase from the Japanese ostracod, *Cypridina hilgendorfii* is strongest and lasts longest in water saturated with hydrogen from which other gases, including oxygen, had been discharged. The intensity of light produced by a luciferin-luciferase suspension of this animal was weakest and lasted least in water saturated with oxygen. Although Kanda admitted that very little oxygen might have been present in spite of elaborate precautions, he concluded that the produc-

tion of light by *Cypridina hilgendorfii* is not the result of oxidation. Four years prior to Kanda's work, Harvey's (1916a) experiments, in which oxygen was replaced by hydrogen, showed that oxygen is necessary for light production in *Cypridina hilgendorfii.* Harvey, then, also called attention to the fact that every other organism studied was found to require oxygen for luminescence. In reply to Harvey's criticism, Kanda endeavored to justify his previous results by checking his technique on a Japanese firefly, *Luciola vitticollis.* In this animal no light was produced by the isolated photogenic organs in an atmosphere of pure hydrogen or nitrogen, or in a vacuum. The intensity of light was greatest in an atmosphere of pure oxygen. Kanda thus concluded that his technique was quite irreproachable and that the production of light by *L. vitticollis* is the result of oxidation while that in *Cypridina* is not. Biologists were now faced by a new enigma—why *Cypridina* can luminesce without oxygen while this phenomenon in *Luciola* imperatively requires oxygen. That this problem was only man-made soon became apparent when Harvey (1920) removed all traces of the oxygen present in commercial hydrogen gas by passing the commercial product over hot platinum coils. Under such conditions the oxygen, present as an impurity, combines with an equivalent amount of hydrogen and forms water. When gaseous hydrogen so treated was used, all light production by *C. hilgendorfii* completely disappeared. "The luminescent secretion of *Cypridina hilgendorfii* will still give off much light if hydrogen containing only 0.4 percent oxygen is bubbled through it . . . At 7 mm of oxygen [i. e., 1 vol. percent] the light of *Cypridina* is as bright as if the solution were saturated with air [152 mm of oxygen]" (Harvey, 1919). In 1923, Harvey and Morrison described a method for measuring the concentration of oxygen necessary to allow just perceptible luminescence of luminous bacteria. The value was 1 part by weight of oxygen to 37×10^8 cc of sea water. Shapiro (1934) studied the light intensity of luminous bacteria as a function of oxygen pressure.

More recently the question as to whether free oxygen is necessary for luminescence of the luciferin-luciferase extracts of all luminous animals became reopened (although unfortunately not to any great extent) when Harvey (1926b) and Harvey and Korr (1938), even by the use of the most drastic methods, found that a few animals (or dried extracts of the same) can luminesce without oxygen. These are the Ctenophora, the medusa *Pelagia noctiluca*, and radiolarians. All luminous pennatulids, annelids, echinoderms, arthropods, and cephalopods could not luminesce without atmospheric oxygen. Harvey suggested that, in the former, the oxygen may be bound up by the photogenic granules. It is possible, on the other hand, especially since "stored oxygen" has gained disfavor, that these lower Metazoa are still

capable of a marked truly anaerobic metabolism and that their luminescent reactions partake of this phase of their metabolism.

2. *The mechanism of bioluminescent reactions.*—Unlike the oxidation of foodstuffs, the oxidation of luciferin does not appear to result in an evolution of CO_2, or, at least not enough CO_2 is produced (pH determinations by means of a sensitive potentiometer) during luminescence to saturate the proteins in solution since "the acidity of the luciferin solution, luciferase solution, and the two after mixing was found to be the same, pH 9.04" (Harvey, 1931). Good evidence that the luciferin-oxyluciferin change is a dehydration-hydrogenation reaction is presented by the fact that dry oxyluciferin, when first exposed to atomic hydrogen, produces light upon the addition of a solution of luciferase; otherwise, dry oxyluciferin plus a solution of luciferase does not produce light. Evidently atomic hydrogen is capable of adequately reducing oxyluciferin to luciferin.

The luciferase is not merely a catalyst in the reaction but evidently supplies molecules which may be excited to emit light by the energy released upon the oxidation of luciferin. These activated molecules may thus return to their initial state (Harvey, 1932, 1935). This is indicated by the fact that when the luciferin from one animal can be energized to produce luminescence with the luciferase of a closely related species, the species (or sex) supplying the luciferase determines the color of the resulting luminescence and by the fact that *Cypridina* luciferin, when oxidized alone in aqueous solution, never emits light even though the velocity of its oxidation may be greater than in the presence of luciferase. The decay curve of light intensity in a luciferin-luciferase solution is monomolecular, indicating that only one molecule of luciferin is being transformed (Amberson, 1922). The entire scheme may be expressed thus (Harvey, 1935, 1935a):

(Luciferase accelerates)

(a) Luciferin $(LH_2) + 1/2\ O_2 \longrightarrow$ oxyluciferin $(L') + H_2O$

(b) $L' +$ luciferase $(A) \longrightarrow L + A'$

(c) $A' \longrightarrow A + hv$ (light quanta)

The prime (′) indicates the excited molecules.

The reaction somewhat resembles that of the reduction of methylene blue:

$$MBH_2 + 1/2\ O_2 \rightleftarrows MB + H_2O$$

(reduced methylene blue) (reductants)

Aluminum, zinc, magnesium powders, or other inorganic reducing agents will reduce oxyluciferin to luciferin as they will reduce methylene blue to the colorless compound. In both cases the reactions are reversible. Further evidence that the reaction is similar to the oxidation of a leuco-dye, rather than to the oxidation of a substance like

benzaldehyde by peroxid formation, is that diphenylamine (a negative catalyst for the oxidation of benzaldehyde) has no effect on the luminescence of a luciferin-luciferase reaction (Harvey, 1918, 1928).

Alkali, within limits, favors the oxidation of luciferin to oxyluciferin (by luciferase) with the resultant production of light, while acid favors the reduction of oxyluciferin to luciferin with the consequent decrease in the glow. These facts are in accord with oxidations and reductions in general.

The activity of aerobic oxidases is destroyed by cyanid concentrations of the order of M/10,000. On the other hand, the activity of anaerobic oxidases (oxidases which do not accelerate oxidations produced by molecular oxygen) and of dehydrogenases are not affected by cyanid except in relatively high concentrations of the latter. M/5,000 KCN reduces the luminescence of luminous bacteria to only 20–25 percent but KCN (even M/250) does not influence the luminescence of *Cypridina* luciferin-luciferase. M/20 KCN, while it does not extinguish the luminescence of the *Cypridina* preparation, diminishes its brightness—i. e., presumably decreases the mass of active luciferase (Harvey, 1916a and b, 1917b, 1932). The reason for the almost nil effect of KCN on the action of luciferase—quite apparently an aerobic oxidase—is problematical. Since it has not been possible to prepare luminous extracts of bacteria, fungi, or medusae (Harvey, 1924, 1926b) and since it is known that the bacterial dehydrogenases are closely bound up with cell structure, Harvey (1935) has suggested that luciferase may be a specialized type of dehydrogenase in which oxygen is absolutely required as a specific hydrogen acceptor.

3. *Luciferins and luciferases.* (*a*) *Properties.*—To Dubois belongs the credit for the fundamental discovery of the presence of the substrate, luciferin, and the enzyme, luciferase, involved in luminescence. In 1885 he found that an aqueous extract of the photogenic organ of a beetle will luminesce in the presence of air and that cellular structure is thus not essential for the production of light (exceptions to such a discovery have been noted above). Such an extract was, however, continuously luminescent so long as it endured, there being no periodicity in the production of light. From what has been said concerning the mechanism of flashing, the reason for this is quite apparent. In 1887 (a and b) he showed that bioluminescence requires the presence of at least four substances, the following three of which had already been recognized: (1) Air [oxygen] (Boyle); (2) water (Spallanzani, 1794); and, of course, (3) a photogenic substance(s). By dialysis through celloidin, two separate solutions were obtained from an aqueous extract of the photogenic organs of fireflies. Neither the dialysate nor the residual solution luminesced. When both solutions were mixed light was reproduced. This at once established the

presence of at least two distinct substances. The substance in the residual solution was destroyed at temperatures of 60° C. or above and was insoluble in petroleum-ether or benzene. The substance in the dialysate was relatively thermostable and soluble in water, petroleum-ether, and benzene. Dubois termed the substance in the dialysate, luciferin; and that in the residual solution luciferase, since he soon discovered that the latter substance exhibited the properties of an enzyme—i. e., a protein with catalytic properties.

As first observed by Spallanzani (1794) on luminous medusae, water is necessary for bioluminescence. Kastle and McDermott (1910) dried the photogenic material of a firefly in vacuo over concentrated sulphuric acid. In the dry state no light was emitted. After keeping the material quite dry for over 13 months luminescence was produced upon moistening with water. Similar results were obtained by Harvey (1916a) on *Cypridina hilgendorfii*. In 1918 Harvey dried *Cypridina* rapidly and stored the product. In 1928, when this was powdered and moistened, the luminescence was as intense as in 1918. Even in aqueous solution, if auto-oxidation was impeded, luciferin was noted to remain stable for at least 4 years. Luciferase in solution saturated with NaCl deteriorates more rapidly (Harvey, 1928a).

There was a time when Harvey (1916a, d) contradicted Dubois' work at its very foundations by considering that luciferase itself is the source of light and is not an enzyme causing light production by the oxidation of luciferin. Harvey's statements grew from experiments in which light was obtained from *Cypridina* luciferase by substances incapable of oxidation (e. g., pure NaCl, $MgSO_4$, chloroform, ether, and pilocarpin—all in aqueous solution) which were believed to act as substitutes for luciferin. Harvey thereby adopted new names after deciding that those of Dubois were unfit: (1) "Photogenin" (= luciferase of Dubois), or the light-producer; and (2) "photophelein" (=luciferin of Dubois), or light assister. Upon further work with *Cypridina*, however, Harvey (1918) readopted Dubois' terms of luciferin and luciferase. Harvey's error in this matter lay in his preparation of a luciferin-"free" solution. He allowed a luciferin-luciferase solution to stand in air till all light ceased, when he assumed that the luciferin was consumed, for light was not produced until further luciferin was added. Upon the addition of NaCl, $MgSO_4$, ether, or chloroform (a fine array of diverse substances) to the solution in which the luciferin was supposedly consumed, light was again produced. He later found that a luciferase solution separated from luciferin by dialysis did not act in this manner (see also Kanda, 1920) and therefore concluded that luciferin probably consists of two substances, one of which is set free to be acted upon by luciferase when sodium chlorid, magnesium sulphate, ether, or chloroform are added.

It should be noted, however, that while Harvey had erroneously believed that luciferase was not an enzyme but itself the substance oxidized with the production of light, he was probably quite right, owing to facts stated under the topic on the mechanism of light-production, in believing luciferase to be the main source of light.

Before we leave the question of the effect of inorganic salts on luminescence, it is of interest to note that NaCl and a number of other salts markedly increase the total amount of light emitted during the reaction of a given amount of luciferin (Anderson, 1937). This may have teleological significance as the luminescent reaction, when produced by *Cypridina*, takes place in sea water—a salt solution. "One explanation of the increased light emission in solutions of sodium chloride is that a change occurred in the activated molecule which made it less likely to lose its energy in collisions with the solvent or with added potassium iodide or thiocyanate."

There are luciferin*s* and luciferase*s*. Thus, luciferin from the firefly, *Photuris* (a lampyrid), will produce light with luciferase from the firefly, *Pyrophorus* (an elaterid), and vice versa. But the luciferin and luciferase of *Cypridina*, an ostracod, will not luminesce with firefly luciferase or luciferin, respectively (Harvey, 1919, 1928). Luciferin of the shrimp, *Systellaspis*, will not give light with luciferase of the ostracod, *Cypridina*, nor will *Cypridina* luciferin luminesce with the luciferase of *Systellaspis* (Harvey, 1931a) or of the mollusk, *Pholas* (Harvey, 1919, 1928). Since the luciferases are quite specific, only closely related forms luminesce when their photogens are intermixed. (See also Harvey, 1926a). The spectrum is always the same as that of the animal supplying the luciferase. The significance of this has already been pointed out.

Cypridina luciferin, furthermore, differs from that of the mollusk, *Pholas dactylus* (Dubois, 1913, 1914; Harvey, 1919, 1928), in that the latter will oxidize with light-production when acted upon by various oxidizing agents (e. g., potassium permanganate, hydrogen peroxide, oxyhaemoglobin, but not with nascent oxygen in the absence of luciferase). Extracts of many nonluminous animals will oxidize *Pholas* luciferin with light-production, but not so with *Cypridina* luciferin. "Oxidation of [*Cypridina*] luciferin at anodes of various metals by nascent oxygen or oxidation by colloidal platinum or palladium and oxygen or other oxidizing agents never results in luminescence in the absence of luciferase." Luciferin, in 95 to 99 percent alcohol (in which luciferase is not soluble) will luminesce faintly if heated to 70° C. or if minute amounts of solid $KMnO_4$, disuccinyl peroxid, $K_3Fe(CN)_6$ $PtCl_4$, $PdCl_2$, and Ca hypochlorite are added. These facts do not at all imply that, in bioluminescence, luciferin is the source of light since—

aqueous solutions of luciferin, even if luciferase is also present, will not luminesce at this temperature. It is possible that in alcohol the oxidation proceeds at the surface of luciferase particles, which pass the filter paper, suspended in the liquid. The luminescence is not to be compared in brightness with that in aqueous solutions with luciferase, and I mention these results merely as a matter of record, as the only cases where *Cypridina* luciferin alone will luminesce. I do not believe they are necessarily significant for the theory of bioluminescence because so many organic substances luminesce on oxidation with *strong* oxidizing agents (Harvey, 1928).

Various plants contain substances which, when added even to a minute concentration of pyrogallol (even 1: 254,000) + H_2O_2 yield light (Harvey, 1916e). These substances are probably certain vegetable peroxidases.

If one mixes a test tube containing pyrogallol solution + hydrogen peroxide with potato or turnip juice or almost any plant extract, a yellowish luminescence appears. The plant extract loses the power to cause such luminescence on boiling and the peroxidaze will not dialyze. It is, of course, comparable to luciferase and acts on the thermostable, dialyzable pyrogallol-hydrogen peroxide mixture, which is comparable to luciferin . . . . Although many hydroxy-phenol and amino-phenol compounds can be oxidized by peroxidase and hydrogen peroxide, only pyrogallol and gallic acid will oxidize with light production (Harvey).

Table 1.—Properties of luciferase and luciferin

Property	Luciferase	Luciferin (more simple than luciferase)
Salting out:		
Saturation with NaCl	Not precipitated	Not precipitated.
½ saturation with $(NH_4)_2SO_4$	Slightly precipitated	Do.
Saturation with $(NH_4)_2SO_4$	Completely precipitated	Nearly completely precipitated.
Solubility:		
Ethyl alcohol 90 percent	Insoluble	Soluble.
Ethyl alcohol 70 percent	do	Do.
Ethyl alcohol 50 percent	Slightly soluble	Do.
Acetone 90 percent	Insoluble	Do.
Ether	do	Insoluble.
Chloroform	do	Do.
Xylol	do	Do.
Alkaloidal reagents:		
Phosphotungstic acid	Completely precipitated	Very nearly completely precipitated.
Picric acid	Nearly precipitated	Not precipitated.
Heavy metal salts:		
Basic lead acetate	Completely precipitated	Not completely precipitated.
Acids and alkalis:		
NaOH	Not precipitated	Not precipitated.
Trichloracetic acid	do	Do.
HCl, after 16 hours boiling	Destroyed	Hydrolysed.
Heat:		
60° C	Irreversibly destroyed	Not destroyed.
Boiling	do	Do.
Boiling with 4 percent H_2SO_4 for 10 hours.	Destroyed	Do.
Boiling for 24 hours with 4 percent H_2SO_4.	do	Destroyed.
Enzyme action:		
Trypsin, erepsin, amylase, urease, sucrase, pepsinase, rennin.	Destroyed only by pepsin (?), by trypsin, erepsin, and something in spleen and liver extracts.	Not destroyed.
Biuret reaction	Positive	Negative.
Dialysis	Will not dialyse through celloidin	Will dialyse through celloidin.
Immunological (Harvey and Deitrick, 1930).	Produces an antibody	Does not produce an antibody.

Table 1 represents a summary of the most important data disclosed by Harvey with regard to the properties of the luciferin and luciferase

of *Cypridina hilgendorfii.* His results have been largely confirmed by Kanda (1921 and 1924). Luciferase exhibits definite protein properties, or, "if luciferase is not a protein it is so closely bound up with a protein that it cannot be separated." Harvey estimated that 1 gm of luciferase can accelerate the oxidation of 10,000 gms of luciferin with the production of light. The fact that the activity of luciferase is gradually diminished in the reaction does not prevent its being classed among the organic catalysts (enzymes). Enzymes, in general, are gradually used up in the reactions they generate and accelerate. The chemical nature of luciferin is not as yet determined and Anderson (1933, 1935, 1936) cannot agree with Kanda (1930) that it is a phospholipid. Nearly complete precipitation by a saturated solution of ammonium sulphate or phosphotungstic acid, insolubility in fat solvents and hydrolysis by prolonged boiling with hydrolic acid, indicate protein properties. On the other hand, solubility in concentrated alcohol and acetone, nondigestibility by proteolytic enzymes, and the absence of a biuret reaction are not protein characteristics.

(*b*) *Distribution in organisms.*—While luciferin has been ascribed to various tissues of *Cypridina hilgendorfii*, luciferase is strictly localized in the photogenic cells (Harvey, 1919). This is in contrast to the phenomena of melanin formation in the elytra of *Leptinotarsa* beetles, where the enzyme tyrosinase is distributed but the substrate localized (Gortner, 1911). In earlier work, Harvey (1916a, 1917a) believed that luciferin, but not luciferase, is also found in nonluminous species of *Cypridina*. On the other hand, Kanda (1920) disagreed with Harvey but agreed with Dubois by finding luciferin solely in the photogenic cells of *Cypridina* and not in nonluminous species. Harvey (1924a) later agreed with this view.

(*c*) *Evolution.*—Bioluminescence is scattered throughout the animal kingdom below the Amphibia but does not seem to carry any apparent phylogenetic significance. As with regard to haemoglobin, therefore, one would look for a certain basic substance present in practically all aerobic cells which may be capable of giving rise to the photogenic substances at random. Now, Harvey (1932) has pointed out that fluorescent substances, such as practically all proteins, are most likely to luminesce, and hence suggested that proteins with an unusually bright "photophore" group are possibly seized in evolution and made to luminesce by the energy of the oxidative dehydrogenation of a luciferin.

Is it merely a matter of chance that luminescence does not occur among fresh-water forms?

PHYSICAL PHENOMENA

1. *Efficiency in light production.*—In the Philosophical Transactions of the Royal Society of London for 1671, volume 1, page 603, is a brief

article bearing the authorship of John Templer and the title, "Some Observations Concerning Glow-worms." The note runs thus: "Mr. T. also *persuaded* himself that he perceived a degree of heat from the insect, when shining in its fullest splendour." In contrast to the foregoing statement we have the following in a recent semipopular article by Parlin (1935): "The ratio between the intensity of the light [of a firefly] thus produced and the amount of matter oxidized is the largest known to science, the efficiency being better than 95 percent! Most of the energy in the latter case is radiated in the form of heat . . . How the firefly can radiate 'cold light,' free from the enormous amount of heat which is present in all man-made sources of light, is a problem which has baffled science for many years, and its solution will revolutionize our lighting industry." As will become apparent below, both of the above viewpoints are unconscious exaggerations.

The efficiency of a light source may be defined in three ways: (1) The *radiational efficiency,* or the percentage of visible wave-lengths in the total amount of radiation emitted, i. e., the amount of visible radiation emitted divided by the total (heat, visible, and actinic) radiation; (2) the *subjective radiational efficiency* obtained by taking into account the sensibility of the eye to different wave lengths, i. e. (visible radiation $\times$ visual sensitivity)$\div$ total radiation; or (3) by the amount of light produced in relation to a given expenditure of energy, i. e., the *total efficiency.* Since the amount of heat evolved by a firefly during luminescence, in excess of the basal metabolic level, or by an in vitro luciferin-luciferase system has not been amenable to measurement even by use of most refined technique (Langley and Very, 1890; Langley, 1902; Coblentz, 1912) and since photography and other methods have shown that apparently all the waves emitted are within the visible region (see below), the radiational efficiency of bioluminescence appears to be 100 percent. Harvey has pointed out, however, that it can be calculated that the amount of heat evolved from the luciferin-luciferase concentrations so far used exceeds the limits of error of available methods. At this point, Franklin's statement, "being only discovered when separating," mentioned at the beginning of this article, is symbolic. A work of great significance at this point is that in which Harvey (1927a, 1935) showed that, for the production of only one quantum of light of $\lambda=0.48\mu$ in an in vitro system of *Cypridina* luciferin-luciferase, about 100 molecules of oxygen must react with the luciferin. The total efficiency of such a reaction would thus be only about 1 percent, i. e., well below the total efficiency of a number of man-made sources of light, including the incandescent ones (see Hodgman, C. D. and N. A. Lange: Handbook of Chemistry and Physics). The total efficiency of luminescences in general is not as great as is commonly imagined. Thus, the efficiency of radioluminescence (radium+ZnS) is about 1 percent (Hess, 1922); of phospho-

rescence is only 0.015 percent (Adams, 1924). "If the efficiency of other chemiluminescences proves to be as low as this, the commercial significance of luminescence seems doubtful, to say the least. What we really need in the case of luminous animals is a determination of the heat of oxidation of luciferin together with the quantity of light produced per calorie, in order that the efficiency may be calculated" (Harvey, 1924a). Now, the total efficiency of an acetylene flame is about 17.7 percent; that of a sodium arc light about 60 percent; that of a carbon filament about 4.54 percent (cf. Hodgman and Lange, loc. cit.). To say that "an area of firefly light 6 feet in diameter on the ceiling of a room 9 feet high would give ample illumination for reading or drawing on a table 3 feet high" (Harvey, 1931c) is of intrinsic interest but is not adequate in convincing an illuminating engineer who is interested in efficiency. In various circumstances, however, a hot flame is not desirable and may be dangerous, while luminescence would be harmless

2. *Intensity of the light.*—The intensity of bioluminescence is measured by a sensitive photoelectric cell and compared with that of a standard lamp. In an in vitro suspension of luciferin-luciferase, the intensity of light varies directly with the concentration of the suspension and with the temperature within limits (Q_{10°=ca. 2.74; Amberson, 1922). Even as little as one gram of the dry photogenic material of *Cypridina hilgendorfii* will yield visible light when suspended in 1,700,000,000 gm (or cc) of water (Harvey, 1916a). The maximum brightness of a prothoracic light organ of the intact firefly, *Pyrophorus*, is 0.0002 candle at 20° C. (Harvey and Stevens, 1928). Coblentz (1912) recorded an intensity variation for the firefly, *Photinus pyralis*, varying between 0.020 and 0.0025 candle with the predominating value at about 0.0025 candle. This insect will sometimes glow steadily with a glow as low as 0.000020 candle in intensity (Harvey, 1919). The average brightness of *Photuris pennsylvanica* is about 0.00067 candle (Parlin, 1935). During the Spanish-American war, Maj. Gen. W. C. Gorgas, according to Parlin, "used the light from a bottle of fireflies to carry out an operation."

3. *Wave lengths represented.*—All light waves emitted by bioluminescence are, so far as known, within the range of the visible spectrum. The light produced by the firefly, *Photinus* (Harvey, 1919), extends only to the beginning of the blue, forming a band through the red to the end of the green with a wave-length range of 6700 A. to 5100 A. Other fireflies exhibit similar ranges (Pasteur, 1864; Young, 1870; Langley and Very, 1890; Ives, 1910; Ramdas and Venkiteshwaran, 1931; Buck, 1937a, b). In the elaterid, *Pyrophorus plagiophthalmus* (Buck, 1937b), the spectrum of the thoracic organ extends from 5075 A to 6400 A.; that of the abdominal organ, from 5350 A. to 6400 A.

In a classical work, Langley and Very (1890), by comparing the spectrum of the firefly, *Pyrophorus noctilucus*, with a solar spectrum of equal intensity, showed that the brevity in extent of the luminescent spectrum is not due to weakness of the red and blue rays but to their absence (limits: λ=4680 A. to λ=0.640 A.).

In the firefly and in ostracods, at least, a rise in temperature shifts the spectrum toward the longer wave lengths, i. e., toward the red (Macaire, 1821; Polimanti, 1911; Harvey, 1924, 1927b). This condition is true both in vivo and in vitro. Harvey (1927b) has suggested that this may be due to a change in the aggregation state of the colloidal particles of the luciferin.

SUMMARY

1. A luminescent body is one which radiates light at a low temperature and the light of which is not the result of (high) temperature.

2. Bioluminescence is a form of chemiluminescence and, except for certain primitive Metazoa, requires free oxygen.

3. Among arthropods, light-producing organs occur in various crustaceans, centipedes, and insects.

4. Unlike centipedes, luminescence in beetles serves for sexual attraction.

5. Bioluminescence is controlled by the oxygen supply to the luminescent cells. As a result of nervous stimuli (which are often periodical), the metabolic rate of the photogenic cells is presumably raised with the consequent liberation of metabolites. The latter, by raising the osmotic pressure of the tissue fluids, as evidence indicates, presumably would cause a withdrawal of fluid from the tracheoles of the photogenic cells and would, thus, supply the cells with more oxygen.

6. There are several luciferins and luciferases. The latter group not only catalyze the oxidation of luciferin but evidently become activated by the process and thus emit light in reverting to the original state.

7. Under conditions which simulate the biological, the oxidation of luciferin will not produce light except when reacting with luciferase.

8. The total efficiency of bioluminescence is apparently very low, being of the magnitude of approximately 1 percent. The *radiational* efficiency of bioluminescence may prove to be the highest that is known to science.

9. All light waves emitted are well within the range of the human-visible spectrum (λ=0.390 to 0.810μ). The luciferase and not the luciferin determines the type of spectrum in bioluminescence.

The writer is much indebted to Prof. E. Newton Harvey (Princeton University) and Dr. John B. Buck (Carnegie Institution) for having read and criticized the above article before its final printing. Needless to say, however, all responsibility falls on the author.

LITERATURE

ADAMS, E. Q.

1924. The luminous efficiency of chemi-luminescent reactions. Physical Rev., vol. 23, p. 771.

ALLARD, H. A.

1918. Rhythmic synchronism in the chirping of certain crickets and locusts. Amer. Nat., vol. 52, p. 548.

AMBERSON, W.

1922 a. Kinetics of the bioluminescent reaction in *Cypridina*. I. Journ. Gen. Physiol., vol. 4, p. 517.

1922 b. II. Ibid., vol. 4, p. 535.

ANDERSON, R. S.

1933. Chemical studies on bioluminescence. I. Quantitative determination of luciferin. Journ. Cell. Comp. Physiol., vol. 3, p. 45.

1935. II. The partial purification of *Cypridina* luciferin. Journ. Gen. Physiol., vol. 19, p. 301.

1936. III. The reversible reaction of *Cypridina* luciferin with oxidising agents and its relations to the luminescent reaction. Journ. Cell. Comp. Physiol., vol. 8, p. 261.

1937. IV. Salt effects on the total light emitted by a chemi-luminescent reaction. Journ. Chem. Soc., vol. 59, p. 2115.

BABÁK, E.

1921. Die Mechanik und Innervation der Atmung. Arthropoden. In Hans Winterstein's Handb. Vergl. Physiol., vol. 1, No. 2, pp. 326–534.

BONGARDT, J.

1903. Beiträge zur Kenntniss der Leuchtorgane einheimischer Lampyriden. Zeitschr. Wiss. Zool., vol. 75, p. 1.

BOYLE, R.

1667. Experiments concerning the relation between light and air in shining wood and fish. Philos. Trans. Roy. Soc., vol. 2, p. 206.

BROWN, E. S., and KING, C. V.

1931. The nature of the photogenic response of *Photuris pennsylvanica*. Physiol. Zool., vol. 4, p. 287.

BUCHNER, P.

1914. Sind die Leuchtorgane Pilzorgane? Zool. Anz., vol. 45, p. 17.

1926. Tierisches Leuchten und Symbiose. 58 pp. Berlin.

BUCK, J. B.

1935. Periodicity and diurnal rhythm in the firefly, *Photinus pyralis*. Anat. Rec., vol. 64, suppl., p. 66.

1935 a. Synchronous flashing of fireflies experimentally induced. Science, vol. 81, p. 339.

1937. Studies on the firefly. I. The effects of light and other agents on flashing in *Photinus pyralis*, with special reference to periodicity and diurnal rhythm. Physiol. Zool., vol. 10, p. 45.

1937 a. Studies on the firefly. II. The signal system and color vision in *Photinus pyralis*. Physiol. Zool., vol. 10, p. 412.

1937 b. Spectral composition of the light emitted by Jamaican fireflies. Anat. Rec., vol. 70, suppl., p. 114.

1937 c. Flashing of fireflies in Jamaica. Nature, vol. 139, p. 801. London.

1938. Synchronous rhythmic flashing of fireflies. Quart. Rev. Biol., vol. 13, p. 301.

CARPENTER, W. B.

1854. Principles of comparative physiology. 770 pp., London.

Coblentz, W. W.
1912. A physical study of the firefly. Carnegie Inst. Washington Publ. No. 164.
Cook, O. F.
1900. Camphor secreted by an animal, *Polyzonium*. Science, vol. 12, p. 516.
Creighton, W. S.
1926. The effect of adrenalin on the luminescence of fireflies. Science, vol. 63, p. 600.
Dahlgren, U.
1915–16. The production of light by animals. Journ. Franklin Inst., vol. 180, pp. 513, 717; vol. 181, pp. 109, 243, 377, 525, 659, 805.
1917. The production of light by animals. Ibid., vol. 183, p. 323.
Deegener, P.
1928. Respirations-organe. Ch. 5, *in* Shröder's Handb. d. Entomologie, vol. 1, 1426 pp.
Dubois, R.
1885. Fonction photogenique des Pyrophores. C. R. Soc. Biol., vol. 37, p. 559.
1886. Contribution a l'étude de la production de la lumière par les êtres. Les Élaterides lumineux. Bull. Soc. Zool. France, Année II, p. 1.
1887 a. Note sur la fonction photogénique chez les Pholades. C. R. Soc. Biol., vol. 4, p. 564.
1887 b. De la fonction photogénique chez la *Pholas dactylus*. C. R. Acad. Sci., vol. 105, p. 690.
1913. Mécanisme intime de la production de la lumière chez les organismes vivantes. Ann. Soc. Linn. Lyons, vol. 60, p. 81.
1914. De la place occupée par la biophotogénèse dans la série des phénomènes lumineux. Ibid., vol. 61, p. 247.
1914 a. La vie et la lumière, Paris, cf. Harvey, 1919.
Emery, C.
1884. Untersuchungen über *Luciola italica*. Zeitschr. Wiss. Zool., vol. 40, p. 338.
1885. La luce della *Luciola italica*, osservata col Microscopio. Bull. Soc. Entom. Ital., vol. 17, p. 351; see also Journ. Roy. Micr. Soc., p. 234, 1886.
1886. La luce negli amori delle Lucciole. Bull. Soc. Entom. Ital., vol. 18, p. 406.
Gazagnaire, J.
1890. La phosphorescence chez les Myriopodes de la famille des Geophilidae. Mém. Soc. Zool. France, vol. 3, p. 136.
Geipel, E.
1915. Beiträge zur Anatomie der Leuchtorgane tropischer Käfer. Zeitschr. Wiss. Zool., vol. 112, p. 239.
Gortner, R. A.
1911. Studies on melanin. IV. The origin of the pigment and the color pattern in the elytra of the Colorado potato beetle, (*Leptinotarsa decimlineata* Say). Amer. Nat., vol. 45, p. 743.
von Guericke, O.
1654. (*See* Catalogue of the special loan collection of scientific apparatus at the South Kensington Museum, 1877, London, 1084 pp.).
1672. Experimenta nova (ut vocantur) Magdeburgica de vacuo spatio. Amsterdam, 249 pp.

HANSTRÖM, B.

1928. Vergleichende Anatomie des Nervensystems der wirbellosen Tiere. 628 pp., Berlin.

HARVEY, E. N.

1916 a. Studies on bioluminescence. IV. The chemistry of light production in a Japanese ostracod crustacean, *Cypridina hilgendorfii*, Müller. Amer. Journ. Physiol., vol. 42, p. 318.

1916 b. V. The chemistry of light production by the firefly. Ibid., vol. 42, p. 342.

1916 c. The mechanism of light production in animals. Science, vol. 44, p. 208.

1916 d. The light-producing substances, photogenin and photophelein, of luminous animals. Science, vol. 44, p. 652.

1917 a. Studies on bioluminescence. IV. The chemistry of light production in a Japanese ostracod, *Cypridina hilgendorfii*, Müller. Amer. Journ. Physiol., vol. 42, p. 318.

1917 b. The chemistry of light-production in luminous organisms. Carnegie Inst. Washington, Publ. No. 251, pp. 171–234.

1918. Studies on bioluminescence. VII. Reversibility of the photogenic reaction in *Cypridina*. Journ. Gen. Physiol., vol. 1, p. 133.

1919. The nature of animal light. 182 pp., Philadelphia.

1919 a. Studies on bioluminescence. X. Carbon dioxide production during luminescence of *Cypridina* luciferin. Journ. Gen. Physiol., vol. 2, p. 133.

1920. Is the luminescence of *Cypridina* an oxidation? Amer. Journ. Physiol., vol. 51, p. 580.

1921. A fish, with a luminous organ, designed for the growth of luminous bacteria. Science, vol. 53, p. 314.

1924. Studies on bioluminescence. XVI. What determines the color of the light of luminous animals? Amer. Journ. Physiol., vol. 70, p. 619.

1924 a. Recent advances in bioluminescence. Physiol. Rev., vol. 4, p. 639.

1925. Luminous fishes of the Banda Sea. Nat. Hist., vol. 25, p. 353.

1926 a. Additional data on the specificity of luciferin and luciferase, together with a general survey of this reaction. Amer. Journ. Physiol., vol. 77, p. 584.

1926 b. Oxygen and luminescence, with a description of methods for removing oxygen from cells and fluids. Biol. Bull., vol. 51, p. 89.

1927 a. On the quanta of light produced and the molecules of oxygen utilized during *Cypridina* luminescence. Journ. Gen. Physiol., vol. 10, p. 875.

1927 b. Bioluminescence. Bull. Nat. Res. Council, vol. 59, p. 50.

1928. Studies on the oxidation of luciferin without luciferase and the mechanism of bioluminescence. Journ. Biol. Chem., vol. 78, p. 369.

1928 a. Stability of luminous substances of luminous animals. Proc. Soc. Exp. Biol. Med., vol. 26, p. 133.

1931 a. Chemical aspects of the luminescence of deep-sea shrimps. Zoologica, Sci. Contr. N. Y. Zool. Soc., vol. 12, p. 71.

1931 b. Photocell analysis of the light of the Cuban elaterid beetle, *Pyrophorus*. Journ. Gen. Physiol., vol. 15, p. 139.

1931 c. Cold light. Sci. Monthly, vol. 32, p. 270.

1932. The evolution of bioluminescence and its relation to cell respiration. Proc. Amer. Philos. Soc., vol. 71, p. 135.

1935. The mechanism and kinetics of bioluminescent reactions. Cold Spring Harbor Symposia on Quant. Biol., vol. 3, p. 261.

1935 a. Luciferase, the enzyme concerned in luminescence of living organisms. Erg. Enzymsforsch., vol. 4, p. 365.

Harvey, E. N., and Dietrick, J. E.

1930. The production of antibodies for *Cypridina* luciferase and luciferin in the body of a rabbit. Journ. Immunology, vol. 18, p. 65.

Harvey, E. N., and Hall, R. T.

1929. Will the adult firefly luminesce if its larval organs are entirely removed? Science, vol. 69, p. 253.

Harvey, E. N., and Korr, I. M.

1938. Luminescence in absence of oxygen in the ctenophore, *Mnemiopsis leidy*. Journ. Cell. Comp. Physiol., vol. 12, p. 319.

Harvey, E. N., and Lavin, G. I.

1931. Reduction of oxyluciferin by atomic hydrogen. Science, vol. 74, p. 150.

Harvey, E. N., and Morrison, T. F.

1923. The minimum concentration of oxygen necessary for luminescence by luminous bacteria. Journ. Gen. Physiol., vol. 6, p. 13.

Harvey, E. N., and Stevens, K. P.

1928. The brightness of the light of the West Indian elaterid. *Pyrophorus*. Journ. Gen. Physiol., vol. 12, p. 269.

Heidt, K.

1936. Über das Leuchten der Collembolen *Onychiurus armatus* Tbg. und *Achorutes muscorum* Templ. Biol. Zentralblatt, vol. 56, p. 100.

Heinemann, C.

1886. Zur Anatomie und Physiologie der Leuchtorgane mexikanischer Cucujos (*Pyrophorus*). Arch. Mikr. Anat., vol. 27, p. 296.

Hess, V. C.

1922. Radioluminescence and its technical application. Trans. Illum. Eng. Soc., p. 127.

Hess, W. N.

1921. Tracheation of the light organs of some common Lampyridae. Anat. Rec., vol. 20, p. 155.

Ives, H. E.

1910. Further studies on the firefly. Physical Rev., vol. 31, p. 637.

Kanda, S.

1920. Physico-chemical studies on bioluminescence. I. On the luciferin and luciferase of *Cypridina hilgendorfii*. Amer. Journ. Physiol., vol. 50, p. 544.

1920 a. II. The production of light by *Cypridina hilgendorfii* is not an oxidation. Ibid., vol. 50, p. 561.

1920 b. III. The production of light by *Luciola vitticollis* is an oxidation. Ibid., vol. 53, p. 137.

1921. IV. The physical and chemical nature of the luciferase of *Cypridina hilgendorfii*. Ibid., vol. 55, p. 1.

1924. V. The physical and chemical nature of the luciferin of *Cypridina hilgendorfii*. Ibid., vol. 68, p. 435.

1930. The chemical nature of *Cypridina* luciferin. Science, vol. 71, p. 444.

Kastle, J. H., and McDermott, F. A.

1910. Some observations on the production of light by the firefly. Amer. Journ. Physiol., vol. 27, p. 122.

Kemp, S.

1910. Notes on the photophores of decapod Crustacea. Proc. Zool. Soc. London, p. 639.

de Kerville, H. G.

1890. Les animaux et les végétaux lumineux. 327 pp., Paris.

Koch, A.
1929. Studien an leuchtenden Tieren. I. Das Leuchten der Myriapoden. Zeits. Morph. Ökol. Tiere, vol. 8, p. 241.
von Kölliker, A.
1857. Über das Leuchten der *Lampyris.* Verhandl. d. Wurzb. Phys.-Med. Gesellsch. vol. 8, p. 217. English transl. in Quart. Journ. Micr. Sci., vol. 6, p. 166.
Kuhnt, P.
1907. Das Leuchten der Lampyriden. Ent. Wochenschr., vol. 24.
Langley, S. P.
1902. Annals Astrophys. Observ., vol. 2, p. 5. (Cf. Harvey, 1919.)
Langley, S. P., and Very, F. W.
1890. On the cheapest form of light. Amer. Journ. Sci., 3rd ser., vol. 40, p. 97.
Lund, E. J.
1911. On the structure, physiology and use of the photogenic organs, with special reference to the Lampyrides. Journ. Exp. Zool., vol. 2, p. 415.
Macaire, J.
1821. Mémoire sur la phosphorescence des Lampyres. Journ. de Physique, vol. 93, p. 46.
1822. Ueber die Phosphoreszenz der Leuchtkäfer. Bibl. univers. de Genéve, 1821. Gilbert's Annal., vol. 70, p. 265.
McDermott, F. A.
1912. Observations on the light emission of American Lampyridae. IV. Canadian Entom. p. 309.
1917. Observations on the light emission of American Lampyridae. V. Ibid, p. 53.
Maluf, N. S. R.
1938. The basis of the rhythmic flashing of the "firefly." Ann. Entom. Soc. Amer., Sept.
Mangold, E.
1910–14. Die Produktion von Licht. In Winterstein's Handb. Vergl. Physiol., vol. 3, No. 2, pp. 225–392.
Mast, S. O.
1912. Behavior of fireflies (*Photinus pyralis*?) with special reference to the problem of orientation. Journ. Animal Behavior, vol. 2, p. 256.
1923. Photic orientation in insects with special reference to the drone fly, *Eristalis tenax* and the robber fly, *Erax rubifarbis.* Journ. Exp. Zool. vol. 38 p. 109.
Morse, E. S.
1924. The synchronous flashing of fireflies. Science, vol. 59, p. 163.
Murray, J.
1826. Experimental researches. Glasgow, see pp. 9 and 71; cf. Tiedemann, 1830.
Ofsianikof, P.
1863. Ueber das Leuchten der Larven von *Lampyris noctiluca.* Bull. Acad. Imper. St. Petersburg, vol. 7, p. 55.
Okada, Y. K.
1935. Origin and development of the photogenic organs of lampyrids, with special reference to those of *Luciola cruciata* and *Pyrocoelia rufa.* Mem. Coll. Sci. Kyoto, vol. 10B, p. 209.

OSTEN-SACKEN, Baron.
1861. Die amerikanischen Leuchtkäfer. Stettiner Entom. Zeitung, vol. 22, p. 54.

PARLIN, W. A.
1935. How bright is a lightning bug? Scientific American, vol. 153, p. 15.

PASTEUR, L.
1864. Sur la lumière phosphorescente des Cucujos. C. R. Acad. Sci., vol. 59, p. 509.

PERKINS, M.
1931. Light of glowworms. Nature, vol. 128, p. 903. London.

PETERS, A. W.
1841. Ueber das Leuchten der *Lampyris italica*. Arch. Anat. u. Physiol. u. Vergl. Anat. p. 229.

PIERANTONI, U.
1914. La luce degle insetti luminosi e la simbiosa ereditaria. Rendic. Acad. Sci. di Napoli, fasc. 1 to 4.
1918. Les microorganismes physiologiques et la luminéscence des animaux. Scientia, vol. 23, p. 43.

POLIMANTI, O.
1911. Ueber das Leuchten von *Pyrosoma elegans* Les. Zeitschr. Biol., vol. 55, p. 505.

PRATJE, A.
1923. Das Leuchten der Organismen, eine Übersicht über die neuere Literatur. Erg. Physiol., vol. 21, p. 1.

RAMDAS, L. A., and VENKITESHWARAN, L. P.
1931. The spectrum of a glowworm (Lampyridae). Note. Nature, vol. 128, p. 726. London.

SCHLEIP, W.
1914. Über die Frage nach der Beteiligung des Nervensystems beim Farbenwechsel von *Dixippus*. Zool. Jahrb. Allg. Zool., vol. 35, p. 225.
1920. Über den Einflusz des Lichtes auf die Farbung von *Dixippus* und die Frage der Erblichkeit des erworbenen Farbkleides. Zool. Anz., vol. 52, p. 151.

SCHULTZE, M.
1865. Zur Kenntnis der Leuchtorgane von *Lampyris splendidula*. Arch. Mikr. Anat., vol. 1, p. 124.

SHAPIRO, H.
1934. The light intensity of luminous bacteria as a function of oxygen pressure. Journ. Cell. Comp. Physiol., vol. 4, p. 313.

SNELL, P. A.
1931. The neuro-muscular mechanism controlling flashing in the lampyrid fireflies. Science, vol. 73, p. 372.
1932. The control of luminescence in the male firefly, *Photuris pennsylvanica*, with special reference to the effect of oxygen on flashing. Journ. Cell. Comp. Physiol., vol. 1, p. 37.

SPALLANZANI, L.
1794. Memoria sopra le Meduse fosforiche. Mem. Soc. Ital. Verona, vol. 7, p. 271.
1796. Chimico essame degli esperimenti del Sign. Goettling sopra la luce del fosforo. Modena, p. 119, cf. Tiedemann, 1830.

SUMNER, J. B.
1933. The chemical nature of enzymes. Journ. Nutrition, vol. 6, p. 103.
1935. Enzymes. Ann. Rev. Biochem., vol. 4, p. 37.

114728—39——27

SUMNER, J. B., and DOUNCE, A. L.
1937. Crystalline catalase. Science, vol. 85, p. 366.

TEMPLER, J.
1671. Some observations concerning glowworms. Phil. Trans. Roy. Soc., vol. 1, p. 603.

TIEDEMANN, F.
1830. A systematic treatise on comparative physiology introductory to the physiology of man. Engl. transl. by J. M. Gully and J. H. Lane in 1834, vol. 1, 431 pp. London.,

TONNER, F.
1933. Ein Beitrag zur Anatomie und Physiologie des peripheren Nervensystems von *Astacus fluviatilis*. Zool. Jahrb., allg., vol. 53, p. 101.

TOWNSHEND, A. B.
1904. The histology of the light organs of *Photinus marginellus*. Amer. Nat., vol. 38, p. 127.

WALTER, A.
1909. Das Leuchten einer terrestrischen Oligochaeten. Trav. Soc. Nat. St. Petersburg, C. R. Séances, vol. 40, p. 136.

WATASÉ, S.
1895. Physical basis of animal phosphorescence. Biol. Lectures, Woods Hole.

WELSH, J. H.
1938. Diurnal rhythms. Quart. Rev. Biol., vol. 13, p. 123.

WHEELER, W. M., and WILLIAMS, F. X.
1915. The luminous organ of the New Zealand glowworm. Psyche, vol. 22, p. 36.

VON WIELOWIESKI, H. R.
1882. Zur Kenntniss der Leuchtorgane von Lampyriden. Zeitschr. Wiss. Zool., vol. 37, p. 354.
1889. Beiträge zur Kenntniss der Leuchtorgane der Insekten. Zool. Anz., vol. 12, p. 594.

WIGGLESWORTH, V. B.
1929. A theory of tracheal respiration in insects. Nature, vol. 124, p. 986. London.
1930. A theory of tracheal respiration in insects. Proc. Roy. Soc. London, vol. 106B, p. 229.
1931. The respiration of insects. Biol. Rev., vol. 6, p. 181.
1932. The extent of air in the tracheoles of some terrestrial insects. Proc. Roy. Soc. London, vol. 109B, p. 354.

WILLIAMS, F. X.
1916–17. Photogenic organs and embryology of lampyrids. Journ. Morph., vol. 28, p. 145.

YOUNG, C. A.
1870. Spectrum of the firefly. Amer. Nat., vol. 3, p. 615.

THE BLACK WIDOW SPIDER [1]

By Fred E. D'Amour, Frances E. Becker, and Walker Van Riper
Research Laboratories, University of Denver

[With five plates]

INTRODUCTION

This study was undertaken somewhat in the nature of a summer diversion. Our interest in the black widow spider was first aroused by the work of Blair (1934) which received considerable publicity during the winter and spring of 1934. When it was found that these spiders were fairly numerous in and around Denver, and a search of the literature indicated that many points concerning their life history and the properties of their venom were not definitely established, a modest research program devoted to their study seemed to promise considerable enjoyment, even though the results might not have an exceedingly great scientific value. Since we could hardly hope to make a specialized study in any one particular field, we decided to explore all of them a little. In consequence, this paper gives findings covering various aspects of the problem. In the first part the appearance of the spider is described, and observations concerning its natural history recorded. In the second, studies concerning the toxicity of the venom, its chemistry, immunology, toxicology, and pathology are reported. Most of the experiments herein reported were carried out during the summer of 1934. However, delay in publication permits inclusion of certain observations and experiments conducted during 1935. The total number of spiders collected has been about 6,500, and some 500 rats have been used.

The literature up to 1932 has been adequately reviewed by Bogen (1932); reference to other important work will be made in the appropriate place.

NATURAL HISTORY

Spiders have a life that is vivid and intense, though so unobtrusive that we usually do not see them, or at most pay little attention to them. Specialists find them fascinating as a group because of their anatomical peculiarities, their production of silk, and their habits of

[1] Reprinted by permission, with some omissions, from The Quarterly Review of Biology, vol. 11, No. 2, June 1936.

preparing snares for prey. Laymen are but little interested in spiders because their apparent economic value is negligible. The average person is likely to have an active dislike, if any feeling at all, for spiders. This dislike is not based on justifiable fear. The effect of the bite of a spider has long been a question. The Tarantula, a small wolf spider of southern Europe, figured in early legends because of the music and extravagant bacchic display designed to incite the patient to the violent dancing which was thought to be the sole cure for its bite.

The only other type of spider that has gained a wide and infamous reputation is *Latrodectus*, a genus of the family Theridiidae. Stories of the deadly nature of the bites of these spiders are current among the peoples of all the regions of the world in which they occur. It is difficult to believe that there is no basis in fact for the similar beliefs that have grown up in such widely separated regions as Europe, America, Madagascar, New Zealand, Algeria, and the West Indies. Arachnologists of the old school were inclined to believe that the stories were based on mistaken evidence. Even today some maintain that the reports of the venomous qualities are greatly exaggerated. In the case of *Latrodectus*, incomplete observation gives conflicting evidence. There are authentic reports of bites of this genus of spider being followed by no harmful results. There are equally authentic reports of fatalities, or of more or less serious and disagreeable symptoms, followed by recovery.

The divergence of opinion in regard to the effect of the bite has a simple and reasonable explanation. All spiders have poison glands, which open near the tips of the fangs of the chelicerae. The contents of the poison sac are expelled by muscular action, undoubtedly voluntary on the part of the spider. A "bite," therefore, does not necessarily imply the injection of the venom, but might be entirely harmless. The injection of varying amounts of venom would explain the gradations in the seriousness of the consequences. Nothing but carefully controlled laboratory experiments can give conclusive evidence in a question of this sort.

The fact that the spider has many common names indicates an enforced recognition. The natives of Madagascar know their two species as "Vancoho" and "Mena-vedi." The New Zealand species is the "Katipo." *Latrodectus 13-guttatus* of southern Europe is known as the "Malmignatte." The common American species, *Latrodectus mactans*, was the "Pokomoo" of the Indians, who knew the potency of its venom for making poisoned arrows. Other common names for this spider are the "Black Widow," the "Hourglass," or "Shoebutton" spider.

The Standard Dictionary says that the derivation of *Latrodectus* is apparently from two Greek words meaning "pay received." Jaeger

(Dictionary of Latin Combining Forms Used in Zoological Names) derives it from *latro*, Greek, a robber; and *dect*(*o*), Greek, to bite, biting, a biter; hence, *Latrodectus*, a robber-biter. *Mactans* is a Latin word meaning "murderous."

DISTRIBUTION

The most recent review of the distribution of the black widow which has come to our attention is that of Burt (1935). This study, combined with that of Bogen, leaves only the following States from which the black widow has not been reported: Oregon, Minnesota, Iowa, Missouri, Wisconsin, Illinois, and Vermont. It is almost certainly present in Oregon; in fact, very probably it will be found in every State of the Union. According to Phillip (1935), Canadian records are available for the Provinces of Alberta, British Columbia, Manitoba, and Ontario, and southward its range in the mainland extends at least to Peru. The species has also been reported from the West Indies.

HABITAT

The web of the black widow is an irregular structure, made of coarse, elastic, tough silk. There is usually a central nest or pocket about the size of one's finger to which the spider retreats when she is frightened, and to which she carries many of her meals. The web is evidently being constantly renewed and repaired, as the silk in an abandoned web is dull in appearance, brittle, and weak, and easily distinguished from the silk in an occupied web. The structure may be of no greater extent than the mouth of a gopher hole, or as much as a yard each way on the surface of a bank, probably being enlarged with the constant renovation. Once the widow has established her web, she is not likely to be found outside of it unless by accident or intent some superior force drives her out. When this happens, she shows her discomfort and fear by timid and awkward actions. With the onset of cold weather, however, many reports have reached us of spiders crawling about on walls and floors of dwellings. Apparently the cold has driven them inside and they are hunting a more favorable winter residence.

The location of the web seems to be largely a matter of chance, though in our locality some favorite sites are permanent holes or fissures in a bank, such as the excavations made by swallows in a clay bank; in brick, rock, or trash piles; in sheds, garages, outbuildings, and basements; under loose rocks and in eroded holes in granite; in tile roofs, etc. Webs and spiders have been found in abandoned birds' nests in the pine trees of the foothills. Recently we found the whole south side of a new country house in the suburbs of Denver harboring young widows of this season in every possible retreat behind shutters,

rain spouts, etc. Webs have been observed in the prickly pear cactus, where they spread about in the branches of the plant, with the central nests in the trash on the ground. In the summer of 1934, perhaps owing to the dryness, these spiders seem to have invaded the residential districts in unusually large numbers, and one of us actually found a mature black widow ensconced behind some books in the library. Reports have come to us of their being found commonly in box cars and a communication from fruit growers on the western slope of the Colorado Rockies stated that grapes were going to waste because pickers refused to work among the spider-infested vines. We have seen the black widow or had reports of her in all parts of Colorado. One was collected at an altitude of 8,000 feet near Buffalo Park, the record altitude so far as our personal experience goes, and we collected specimens both in 1934 and 1935 at an altitude of about 7,300 feet in Estes Park. Recently we have received from a trustworthy source a record of one taken near the village of Estes Park at an altitude of 8,200 feet.

It is evident from the above statements that the spider recognizes few geographic barriers except extreme cold and is also easily satisfied with her local surroundings. At the same time, we have found certain particular locations very densely populated and it would appear that these are the most favorable in insuring survival. As stated, we have collected approximately 6,500 spiders. By far the greatest number of these were captured in the foothills country between Denver and Colorado Springs. The hillsides are of disintegrating limestone, forming fissures and clefts in the cliff faces, and with many boulders on the gentler slopes. On the south slopes of these hills and canyons, nearly every cleft and hole in the cliff has a web across its mouth, nearly every boulder a web along its lower margin. The insect life is not particularly abundant, but in such regions as this one can collect several hundred spiders within a few hours. It should be noted, however, that the size of the spider seems to be in direct proportion to the size of the rock, and to collect large specimens one must have the fortitude to turn over large rocks

The web serves as a snare for the prey on which the spider feeds—flies, beetles, grasshoppers, and the other insects that blunder into it. We have even observed a small mouse entangled and several times have seen the large western cicada, which is nearly as big as a mouse, a victim. Usually whatever touches the web is securely caught almost at the first contact, and its struggles only tie it the more tightly. Large grasshoppers, however, can kick themselves free and require prompt and energetic measures on the part of the spider. She belongs to the family of "comb-footed" spiders which are distinguished by the presence on the tarsus of the fourth pair of legs of a distinct comb, consisting of a row of strong, curved, and toothed setae. The

comb is used for flinging silk, in an almost liquid state, over the entangled prey. It is interesting to see the technique employed in subduing one of the larger grasshoppers, an animal considerably bigger and many times stronger than the spider. What she does is to hog-tie the powerful jumping legs of the victim and after submission is gained in this way she takes her time about administering the fatal bite.

HIBERNATION

In the vicinity of Denver we have been able to collect specimens in every month of the year. The degree of activity shown by spiders collected in the winter months appears to depend on the temperature; if it is warm, individuals captured behave about as they do in summer; if it is cold, they are more or less torpid. They have been found in winter in all the common places, and we have never observed the slightest evidence of special preparation against the cold—nothing in the way of additional web or better protection for the nest. Many of those found under rocks and in trash heaps appear to have made no webs of any kind. In December last year, after a heavy snow with cold nights, we picked up a specimen from the bottom of a pile of tumbleweeds, about as wet and cold a spot as one could imagine. Later, in an unheated room, where half a dozen recently collected spiders were exposed to a temperature of 10° below zero in a sudden cold snap, all were frozen.

METHODS OF COLLECTING

Latrodectus is ready both by day and by night for any passing victim and at night is easily spotted with a flashlight. An easy method of collecting from holes in banks and similar places is to tie a beetle to a string 18 inches or so long with the other end of the string attached to a stick of handy size. When the beetle is dropped into a web, if the spider is hungry, she will at once rush out to capture the struggling insect. Web and spider may then be struck down and the spider transferred by means of forceps to the collecting bottle. Sometimes one may pull out web and egg sacs so that they dangle just outside the hole. After some time the female may frequently be caught outside in the act of rescuing her eggs and repairing the damage to the web. During the capture of the widow she almost always exhibits the cataleptic reflex, "playing possum," a protective habit that is common to almost all kinds of spiders, and when picked up by a leg with the forceps she is likely to cast the leg, another protective device that is familiar to spider observers everywhere.

TEMPERAMENT

Dining on the crumbs from the widow's table is a tiny, long-legged commensal, *Psilochorus utahensis* (Chamberlin), identified for us by Dr. W. J. Gertsch of the American Museum of Natural History, which is commonly found in black widow webs in this locality, often half a dozen or so, males and females, to a web, the females carrying their eggs in the chelicerae. With this exception the widow is generally found alone, since her fierce and predaceous habits cause her to kill any insect invader or be killed. The "killer instinct" is apparent in the following description of a typical conflict observed in a web located in a well-lighted hole, about eye level, in a brickyard bank. The occupant was a large female with two egg sacs in the upper part of the web. She was hanging, back down, on one of the sacs—a characteristic position. A small mirror was used to shine light into the hole so that everything might be clearly seen. The observer placed another widow, previously collected, into the outer part of the web. There was no movement for a moment; then the alien oriented herself and moved a short distance into the web. The occupant countered by leaving the egg sac and advancing a spider's length toward the interloper. Both advanced and stopped alternately until they approached each other in the center of the web. All their movements were deliberate and cautious. There was a moment of absolute stillness, then, with a motion too quick for the eye, the occupant threw a shower of thick, sticky silk, which spurted from the spinnerets at the tip of the abdomen and was flung over the invader by a skillful manipulation of the hind legs. The victim was rapidly rolled over and over in a net until it was completely covered like a mummy. It was only then, when the risk was past and all secure, that the poison bite was administered.

Contests staged in the laboratory established the fact that a bite upon another spider causes paralysis immediately, but does not necessarily produce death. Victims removed from the web after they were helpless and all prepared for the victor to begin feeding were found to recover their powers of motion after several hours, and to be apparently normal the next day. In contrast to the fierce nature of the spider toward others of her kind is the extreme timidity which she exhibits toward unnatural disturbances of her web, such as might be caused by a collector. At the first molestation of the web, she retreats with incredible speed into the central nest, and does not venture out again for hours. We have never seen the slightest attempt at defense, to say nothing of aggression, on her part under such circumstances.

MEANS OF DISPERSAL

Spiders show two definite tropisms. When they are young they are negatively geotropic, tending to climb upward; at all stages they are

negatively heliotropic, tending to move away from the light. The geotropism of the young provides a means of dispersal. Once the maiden flight has been effected and dispersal accomplished, the spiders no longer exhibit the tropism. The following observations on the dispersal of the spiderlings were made by us.

A glass tube about 1¼ inches in diameter and 3 feet long, enclosing a piece of bamboo of the same length wound with raffia, was closed with cloth at both ends after a newly made egg sac had been placed inside on the bottom cloth. The whole contrivance was then set upright in a retort stand. The bamboo inside the glass tube would furnish the spiderlings something to climb on should they have the instinct to do so after emergence from the sac. About 4 weeks after the spinning of the sac, there were two little swarms of 50 or 60 spiderlings each at the base of the tube near the sac. During the day they all climbed their artificial tree and swarmed at the top of the tube. The next morning the apparatus was carried out into the country, the top cover removed, and the length of the artificial tree increased by a 3-foot stick. Immediately about 15 of the little spiders detached themselves from the swarm and intently climbed to the very tip of the new stick. The sun was shining and a little breeze blowing from the south. Suddenly a tiny mite was snapping about in space 18 inches or 2 feet from the stick. It was a spiderling waving in the breeze at the end of a gossamer drag-line which it had spun as it was blown from its moorings. Then the spider was observed to be working its way back along the line; not drawing in the line but leaving it out, possibly doubling it. The adventurer reached his dock again, leaving the silken thread flapping in the breeze. Suddenly the line broke at its base, or was cut by the spiderling behind him, and he sailed away into space too rapidly for the eye to follow the course very far. This happened again and again, till of the original 15 adventurers only 2 or 3 remained. This explains the disappearance of the young spiders from the maternal web so soon after emergence, and explains also their being found later in life in curious places to which chance blew them on their initial flight.

When the young spider ends its voyage we must imagine that it seeks the first hole or crack available as shelter. Here it spins a web not unlike that of the mother, but on a small scale, catches its prey in the same way, and if circumstances are propitious, sets up a permanent establishment.

ENEMIES

In spite of the fact that the poison of the widow is deadly to all small animals, she has a number of natural enemies. We have observed the vireo feeding the spider to her nestlings, and pigeons and chickens may eat it with impunity, the latter with apparent relish.

Field mice and related mammals probably take the spider when they find her, since we have never observed one under a rock that shelters rodents. Possibly some of the hunting spiders can overcome the widow, although in laboratory observations she has always prevailed over any other spider put in with her.

In all the thousands of spiders that we have handled we have never noticed a single case of a disease or parasite that appeared to be destructive of the mature spider. In a small percentage of cases (3 out of 207 in one series) we have found the egg sacs parasitized by a small ichneumon which the late Professor Crosby, of Cornell, identified for us as *Gelis* sp., relatives of which are widely known as parasites of spider cocoons. The flies oviposit on or in the egg sac, the larvae consume the contents of the sac, pupate inside the sac, and the flies emerge. We have also found, in the debris of the spider's web, in the empty egg sacs and in various other similar places, the active and omniverous larvae of one of the Dermestid beetles, the common museum pests. Whether these grubs are only scavengers cleaning up the waste from the spider's table, or are also capable of destroying the living eggs, we have not been able to determine as yet. But we suspect that both are true.

There can be no question, however, but that the blue mud dauber (*Chalybion cyaneum* Klug) is a predator on the black widow. We have collected many mud dauber nests and have frequently found immature black widows stored as food for the larvae. Recently Irving and Hinman (1935) have published similar findings. In Lamar, Colo., where black widows have been extremely prevalent the past 2 years, residents have told us that the mud daubers seem unusually scarce. It may be that in nature the mud dauber is one of the chief factors in holding the black widow in check.

EXPERIMENTAL

STUDIES ON TOXICITY

The first problem was to study the toxicity of the venom and to develop a reliable means of assay. Most experimental studies previously reported fall under two heads as far as the source of the material used is concerned. Some workers have proceeded by placing the spider upon a shaved area of the animal used and pinching it with forceps until it bit. Others have used the macerated heads of the spiders as their experimental material. Early in our work we tried both methods, but soon learned that they were unreliable and that consistent results could not be obtained. If one employs the first technic, he encounters several factors which are difficult or impossible to control. The actual amount of venom introduced will obviously be dependent upon the size of the spider, its past history—that is,

how long since it last made use of its poison apparatus and the speed of regeneration of the poison—and upon the degree of anger aroused by the pinching. As will be shown later, even under conditions which one might suppose would excite the greatest degree of anger—that is, after victory in mortal combat with another spider—the glands still contain a considerable amount of venom. It seems likely that the glands are under some degree of volitional control and the amount ejected will depend upon the degree of irritation of the spider. This is supported by the experience of Baerg (1922), who speaks of spiders which bit readily and caused severe symptoms while others attacked only under extreme provocation.

As for the second method, that of using macerated heads as a source of material, if a sufficiently large number of spiders is used, the size and past history factors are averaged and, of course, the question of degree of irritation does not enter. However, anyone who has ever dissected out the venom glands will have noted their toughness and elasticity. Macerating the heads, even though the operation is carried out thoroughly, will certainly fail to crush all glands. An unknown number will escape maceration and will then be discarded with the debris. The following tables illustrate the above points. Table 1 gives the results of actual biting experiments. In these trials spiders

TABLE 1

Weight of rat	Spider	Results
264 gm	Large	No symptoms.
280 gm	do	Comatose all afternoon and night, breathing shallow, hind legs paralyzed. Recovered.
308 gm	Small	Symptoms much like above, in addition, foreleg paralyzed, large swollen area at site of bite. Recovered.
65 gm	Average	Severe paralysis in all legs. Could not use legs, could be slid across table. Breathing became difficult, died after 48 hours.
73 gm	do	No symptoms.
80 gm	do	Slight paralysis, recovered.

were used which had been kept in the laboratory 3 days and had not been fed during that period. These were placed upon shaved areas of the rat's abdomen and excited to bite by being pinched with forceps. The results are seen to be very inconsistent.

In table 2 the results of two experiments are shown in which macerated heads were used, 40 heads being used in each batch. The wide variation in effect no doubt indicates failure to crush and extract all glands.

Comparison of these results with the toxicity curve for venom obtained later indicates that even in the more active preparation a large number of glands must have escaped extraction.

TABLE 2

Batch	Number of rats injected	Amount injected	Percent dead
1	10	Equivalent of 2 spiders	70
1	10	Equivalent of 1 spider	10
2	10	Equivalent of 2 spiders	0
2	10	Equivalent of 1 spider	0

In view of the inconsistent results shown above we adopted the following procedure as a routine method in the preparation of all venom used in the succeeding experiments. No fewer than 20 spiders, in some cases as many as 80 spiders, were used in the preparation of each batch of material, and in this way individual differences were averaged. The spiders were placed under light chloroform anesthesia, the abdomen clipped off and the cephalothorax and legs imbedded in molten paraffin on a microscope slide. Solidification of the paraffin held the spider in a firm mounting. Under the dissecting microscope the skin of the head above the eyes was clipped off; the venom glands were then clearly visible and could be removed with fine forceps. The glands were then placed in physiological salt solution and carefully pulled apart and thoroughly macerated. The glandular debris was transferred to fresh saline, again macerated and washed and discarded. The washings were added to the original solution.

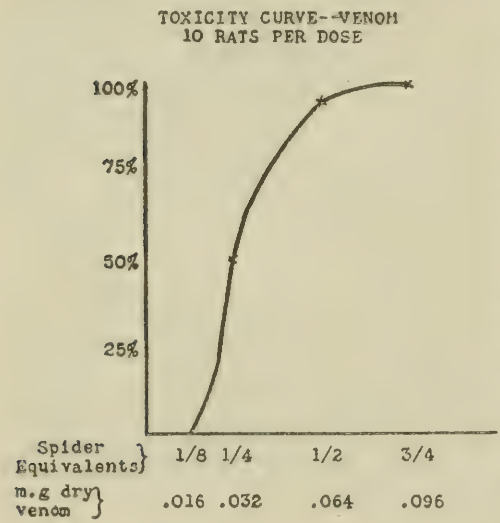


FIGURE 1.

Young rats, 50 to 60 grams in weight, were chosen as test animals, first, because of their availability in this laboratory; and second, because preliminary experiments showed that they were quite susceptible. A relatively small amount of venom would cause death and an adequate amount would produce a chain of symptoms which was a very definite and constant one.

The toxicity curve.—The work of Trevan (1927) on biologic assays in general and the work of Coward and Burn (1927) and ourselves (1930) on the assay of estrin preparations has clearly indicated the necessity of using large numbers of animals in the assay of biologic

preparations in order to overcome the individual variation which exists between animals of the same species, weight, and age. In order to establish the toxicity of spider venom we therefore injected varying amounts into groups of 10 rats per dose. Figure 1 shows the results obtained, with the amount of venom indicated both in fractional parts per spider and in absolute weight.

As will be noted, the average lethal dose—that is, the amount of venom which will kill 50 percent of the rats—is one-fourth the venom contained in the glands of one spider, or 0.032 mg. This is the amount meant when the term "average lethal dose" or "equivalent of one-fourth spider" is used in describing subsequent experiments.

Table 3

Type of injection	Number of rats	Amount injected	Percent dead	Maximum life
Subcutaneous	5	Equivalent of ¼ spider	0	
Do	5	Equivalent of ½ spider	60	36 hours.
Do	5	Equivalent of 1 spider	100	24 hours.
Intraperitoneal	10	Equivalent of ¼ spider	50	12 hours.
Do	10	Equivalent of ½ spider	90	8 hours.
Do	10	Equivalent of 1 spider	100	8 hours.

Mode of injection.—In obtaining the above toxicity curve, as well as in practically all of the later work, intraperitoneal injections were given. A preliminary study, the results of which are shown below, indicated this type of injection to be preferable, inasmuch as the amount of venom necessary to cause death was somewhat less and also the length of time before death occurred was shorter when intraperitoneal injections were given. As we did not know in advance how plentiful the spiders would be, we naturally made use of the method which would require the least expenditure of venom, and having used this method in obtaining the toxicity curve continued with it in further experiments so that the results would be comparable.

Weight of rats.—The weight of the rat is an important factor in the amount of venom necessary to obtain a required result. For reasons given, we used immature rats weighing between 50 and 60 grams. Litters in prospect promised an adequate supply of rats of this size throughout the summer months. No extensive experiment was carried out to discover the ratio of venom to body weight; however, table 4 gives the data on the few trials which were made.

Type of spider.—The spiders used throughout in the work reported elsewhere in this paper were mature females, as indicated by the absence of any markings on the dorsal surface. (See plates.) However, it seemed desirable to investigate the toxicity of immature females and of males as well. For this purpose glands from both groups were obtained in the usual way and injected. The results are given in table 5.

TABLE 4

Number of rats	Weight	Amount injected	Percent killed
10	50–60 gm	Equivalent of ½ spider	90
4	100–150 gm	Equivalent of 1 spider	50
12	200–250 gm	Equivalent of 1 spider	33
8	200–250 gm	Equivalent of 2 spiders	100

These results indicate that the difference in toxicity is qualitative as well as quantitative.

Toxicity of baby spiders.—The eggs of the black widow spider hatch within the egg sac, and there the spiderlings undergo their first molt. It seemed interesting to compare the toxicity of the baby spiders with the eggs from which they came, therefore spiders 7 to 10 days after their emergence from the egg sac were studied, as it was thought that much of the material from the egg would by that time have been utilized. Since it was impossible to dissect out the glands, the spiders were macerated in saline, the debris filtered off, washed in fresh saline and the washings added. Undoubtedly many of the venom glands would not be crushed in this process and the toxicity indicated in table 6 resides in the tissue fluids of the spiders and possibly in unabsorbed egg material.

TABLE 5

Type of spider	Number of rats	Amount injected	Results
Immature females	3	Equivalent of ¼ spider	No symptoms.
Do	3	Equivalent of ½ spider	Do.
Do	3	Equivalent of 1 spider	Do.
Do	2	Equivalent of 1½ spider	Do.
Do	3	Equivalent of 3 spiders	Sick, but recovered.
Do	2	Equivalent of 6 spiders	Very sick, recovered.
Mature males	1	Equivalent of 12 spiders	Practically no symptoms.
Mature females	10	Equivalent of ¼ spider	50 percent killed.

Average length of venom glands:	*Mm*
Mature females	1.75
Immature females	.75
Mature males	.75

TABLE 6

Number of rats	Amount injected	Results
5	Equivalent of 1 spider	Slight paralysis, recovered.
2	Equivalent of 2½ spiders	Do.
2	Equivalent of 5 spiders	Severe paralysis, recovered.
2	Equivalent of 10 spiders	1 died, other very sick, recovered.

Degree of exhaustion following biting.—As previously mentioned, other workers have studied the toxic effects of the venom by causing spiders to bite their victims. Among others, Baerg (1922) describes

experiments done upon rats in which the first bite resulted in severe symptoms, a subsequent bite in less severe symptoms, and the third in no symptoms whatever, from which he concludes that immunization had occurred. As will be shown later, immunization develops much more slowly than these results would lead one to believe. In experiments done upon himself, Baerg obtained almost opposite results, the first bite causing only local pain, whereas the second was followed by a very serious and painful chain of symptoms.

We tested the question of the degree of exhaustion of venom in biting by placing the spiders under conditions where one would expect them to bite their hardest and to inject the maximum amount of venom. These spiders are notoriously cannibalistic. It is a well-known fact and one which we have observed repeatedly, that when two mature females, especially if one is attending an egg sac, are placed in one container, they will fight furiously until one or the other has been bitten and killed. We placed spiders together under these conditions; in the first experiment the victor of one match was matched with another victor; in the second, spiders were used which had only bitten once. The results are shown in table 7.

TABLE 7

	Number of rats	Amount injected	Results
Experiment 1	1	Equivalent of 1 spider	Died.
Do	2	Equivalent of ½ spider	Sick; recovered.
Experiment 2	1	Equivalent of 1 spider	Died.
Do	2	Equivalent of ½ spider	Sick; recovered.

TABLE 8

	Mg
Dry weight of glands from 20 spiders	4.0
Dry weight of debris	1.48
Dry weight of venom	2.52
Dry weight of venom per spider	.126
Dry weight per a. l. d	.032

The spiders in experiment 1 had bitten others twice within a half-hour before being killed, those in experiment 2 had bitten others once within a half-hour before being killed. These results show that the glands still contain a considerable amount of venom—at least one-fourth the total amount—even after the spider has used them twice within the previous half-hour. It should also be stated that where the spider was biting for the second time, the victim usually recovered. No experiments were carried out to determine the length of time necessary for regeneration of venom.

Potency of venom in terms of weight.—The poison glands were removed from 20 spiders and dried in air for 12 hours. They were then weighed. Following thorough maceration in distilled water,

the glandular debris was dried and weighed. The difference between the two weights is taken to represent the dry weight of the venom. This is not entirely correct, since unavoidably some glandular elements were lost in maceration. The figure obtained errs, therefore, on the side of assigning a somewhat lower potency to the venom than is actually the case. Table 8 shows the results.

These results indicate that on the basis of weight the venom of the black widow is extremely potent. In man, the spider bite results fatally in about 5 percent of all cases (Bogen, 1932). The rattlesnake is said to kill in from 15 to 25 percent; the actual amount of venom introduced is, however, much greater in the case of the snake. Experimentally, Calmette found that 0.2 mg of cobra vemon will kill a guinea pig, and Noguchi states that 5 mg of rattlesnake venom will kill a 350-gram guinea pig in 24 hours. The following comparison of the potency of black widow with rattlesnake venom was made. Two specimens of the common prairie rattlesnake (*Crotalus albicans*, Say) were collected, one a male 3 feet long with eight rattles and the other a female 2½ feet long with six rattles. The venom was obtained by pressing upon the glands, then dissecting them out and washing with distilled water and evaporating to dryness. Thirty-two mg of dried venom were obtained from the large snake and 20 mg from the small. The venoms were pooled and assayed. The results are given in table 8a.

As 0.064 mg of spider venom killed 90 percent of injected rats, it appears to be about 15 times as potent on a dry-weight basis.

Table 8a

Number of rats	Amount injected	Percent killed
	Mg	
10	0.75	0
10	1.0	90
10	1.5	100

TOXICOLOGY

Symptomatology.—The effect of the black widow spider venom upon the organism has been variously described by different investigators. In the human, Bogen (1932) has studied a considerable series of cases and finds that the chain of symptoms is a remarkably constant one. The outstanding features in the sequence of events are as follows: The bite itself is not painful, being comparable to a sharp pin prick; a dull numbing pain ascends the extremity bitten, and then localizes itself in the muscles of the chest, back, and abdomen. This pain is excruciating in character. The abdominal wall is boardlike in its

rigidity; except for the absence of local tenderness and the involvement of other muscle groups, the pain resembles that experienced in the case of a ruptured appendix or perforated peptic ulcer. Due to the spasm of the thoracic muscles respiration is difficult. A rise in blood pressure occurs, there is frequently nausea and vomiting, a slight fever and leucocytosis. The general symptoms make their appearance within 4 hours and may last for 2 to 3 days. In fatal cases death occurs in from 18 to 36 hours. The observations are in general agreement with those of Baerg (1922) and of Blair (1934), who permitted spiders to bite them under controlled conditions. Relief from pain seems to be difficult to obtain, relatively large doses of morphine are without much effect; hot baths are very helpful.

In the rat, administration of the venom is followed by paralytic symptoms which are first evidenced by a peculiar stiffness of gait and awkwardness in movement. The hind legs are first affected and the animal walks with the rear elevated. One or both forelegs are next affected and the animal sits in a hunched up position with the forelegs bent and held close to the body. At this time the animal refuses to move unless violently stimulated but can withdraw the foot if the toes be pinched. As regards respiration, we noted a difference in behavior usually depending upon the size of the animal. In immature rats the respiration becomes progressively more and more shallow, the animal lies in a state of coma; as death approaches, the breathing becomes almost imperceptible. In older rats respiration becomes extremely labored. The animal gasps violently for air but is apparently unable to fill the lungs. This labored respiration continues until death occurs. Many rats were autopsied immediately after death. In all cases the lungs collapsed when the thorax was opened, indicating no constriction of the bronchioles, although, as will be noted later, ephedrine appeared to give considerable relief. The auricles were usually beating. There were no gross signs of pathologic changes.

One effect which was invariably produced was an irritation of the lachrymal glands. The eyes watered profusely; they were usually closed or nearly so. There was always an accumulation of bloody serum around the nostrils, frequently in considerable amounts. This happened even when there was no labored respiration. The animals suffered from thirst and in the earlier stages made efforts to drink but were apparently unable to swallow.

DISCUSSION

The questions we have been asked most frequently as the fact of our investigation of the spider became known were these: 1. Are the spiders increasing greatly in numbers? 2. Is the spider changing

114728—39——28

its habits, that is, is it leaving its rural haunts and invading settled communities to a greater degree than before? 3. What methods of eradication are feasible? 4. Does the spider represent a real menace? 5. Is there any effective antidote? 6. What are the possibilities of antivenin? To the first question the authors do not hesitate to give an affirmative answer. This may appear unjustified since this is admittedly the first year in which we have collected the spider. If the black widow were smaller, if its appearance were not so striking, if it were easily confused with some other form, or if it had previously been fairly common, one might hesitate to commit himself. However, as an example, we have a cold box set just outside the laboratory, on the ground level, and opening into the room by means of a window. So far, we have on two different occasions found three spiders at one time and another time two spiders, in webs close to the window. They are visible all the way across the room. When opening the window, one must be blind not to see them. This box has been there for years. We feel morally certain that had spiders ever been in the same location before we would have noticed them.

It is, of course, true that one sees what one looks for, and the newspaper publicity which these spiders have received has caused many more of them to be noticed and reported than would otherwise have been the case. On the other hand, farmers and fruit growers are usually quite observant as to the kind of insects found on their crops and when this year, for the first time, reports are received that tomato growers find the spiders so bad that protective clothing must be worn, when grape growers report that in some places the spiders are so numerous that the pickers refuse to work and the grapes are rotting upon the vines, and peach growers notice many of them in their orchards, the conclusion seems inescapable that they are more numerous this year than ever before.

The second question, relating to an apparent change in the habits of the spider, in that it seems to be invading settled communities to a greater degree, is to some extent dependent upon the first. If the spiders in a given region increase greatly in numbers, their manner of dispersal by wind and their utilization of such means of transportation as box cars would make it inevitable that some would find themselves within towns and cities. Once having become established, their chances for survival and increase are favored. Many of them have been found in basements, garages and similar places where they are protected against the cold to a much greater degree than would be the case out in the open. We believe that the increase in numbers noted during the past summer is due to the mild winter which preceded it; however, cold will not operate as a check upon those which have established themselves in the garages and basements of heated buildings. The conclusion appears inescapable that, unless

drastic methods of eradication are employed, we will have a considerable, and probably an increasing number of these unwelcome guests.

This leads to the problem of eradication. We have tested, under laboratory conditions, several of the more common insecticides. The general conclusion was that such insecticides as Flit and Black Flag, in concentrations sufficient to kill promptly all flies within the room, is without effect upon spiders, as would be expected from the difference in the anatomy of the respiratory organs. Sulphur dioxide, in high concentration, will kill them in time, as will carbon disulphide, though relatively high concentrations and long exposures are necessary. Often the spider appears to be dead and remains so for hours but eventually recovers. Hydrogen cyanide, in the form of cyanogas, is effective, but too dangerous to recommend for general use. The California State Department of Health recommends the use of creosote and crude oil sprays, which would no doubt be effective in certain locations, but are obviously unavailable in vineyards or tomato beds. The spider is far from gregarious in its habits and consequently a given basement or garage will not harbor more than perhaps a half dozen. Our suggestion, when called upon for advice, has been to locate the individual spider, easiest done at night, and destroy it, rather than resort to general fumigation. This advice is valueless for the aforementioned farmer or fruit grower; protective clothing during the picking season and burning of debris afterward is about all that can be suggested.

Does the spider represent a real menace? We have emphasized throughout, in our dealings with the press and public, the fact that the spider is above all extremely timid. We have rarely seen a spider, disturbed in her web, who made any pretense of defense, to say nothing of attacking. They will almost invariably run and hide and remain out of sight in a crevice or hole for hours afterward. The danger lies in accidentally squeezing one when picking up some object to which the spider is clinging, when putting on old clothing left hanging in a shed, or in some similar way. Some children enjoy catching and playing with crawling things, which cannot be done with impunity with the black widow. As to the bite itself, there can be no question of its frequently serious, sometimes fatal, effects. The statement sometimes heard, even from zoologists who should know better, that the bite of a black widow is no more dangerous than that of a mosquito, must, in view of extensive clinical experience, be branded as false and dangerous.

There is, at present, no effective antidote. First-aid treatment might well comprise the application of a tourniquet, free incision and the sucking out of the venom either by means of the mouth or some mechanical device. However, as Bogen has emphasized, the spider

usually lives in filthy surroundings and the danger of infection is consequently great. Thorough sterilization of the site of the wound should therefore precede incision. Further treatment is best carried out in a hospital; it consists mainly of measures taken to alleviate pain, the free use of morphine, hot baths, etc.

BIBLIOGRAPHY

Baerg, W. J.

1922. The effects of the bite of *Latrodectus mactans*. Journ. Parasitol., vol. 9, p. 161.

Blair, Alan.

1934. Spider poisoning. Arch. Internal Medicine, vol. 54, p. 831.

Bogen, Emil.

1932. Poisonous spider bites. Ann. Internal Medicine, vol. 6, p. 375.

Burt, Chas. E.

1935. A review of the biology and distribution of the hourglass spider. Journ. Kansas Ent. Soc., vol. 8, No. 4, p. 117.

Coward, K. H., and Burn, J. H.

1927. Errors in biologic assays. Journ. Physiol., vol. 63, p. 270.

D'Amour, F. E., and Gustavson, R. G.

1930. A critical study of the assay of female sex hormone preparations. Journ. Pharmacol. and Experimental Therapeutics, vol. 40, No. 4, p. 473.

Irving, William G., and Hinman, E. Harold.

1935. Science, vol. 82, No. 2130, p. 395.

Lawson, P. B.

1933. Notes on the life history of the hourglass spider. Ann. Ent. Soc Amer., vol. 26, No. 4, p. 568.

Levy, R.

1916. Contribution à l'étude des toxines chez les araignées. Paris Ann Sci. Nat. Zool., ser. 10, p. 161.

Philip, Cornelius B.:

1935. Arachnidism, black widow spider poisoning. Northwest Medicine, vol. 34, p. 52.

Szu, C., and Wu, H.

1934. Fractional precipitation of serum protein with methyl alcohol. Chinese Journ. Physiol., vol. 8, p. 97.

Trevan, J. W.

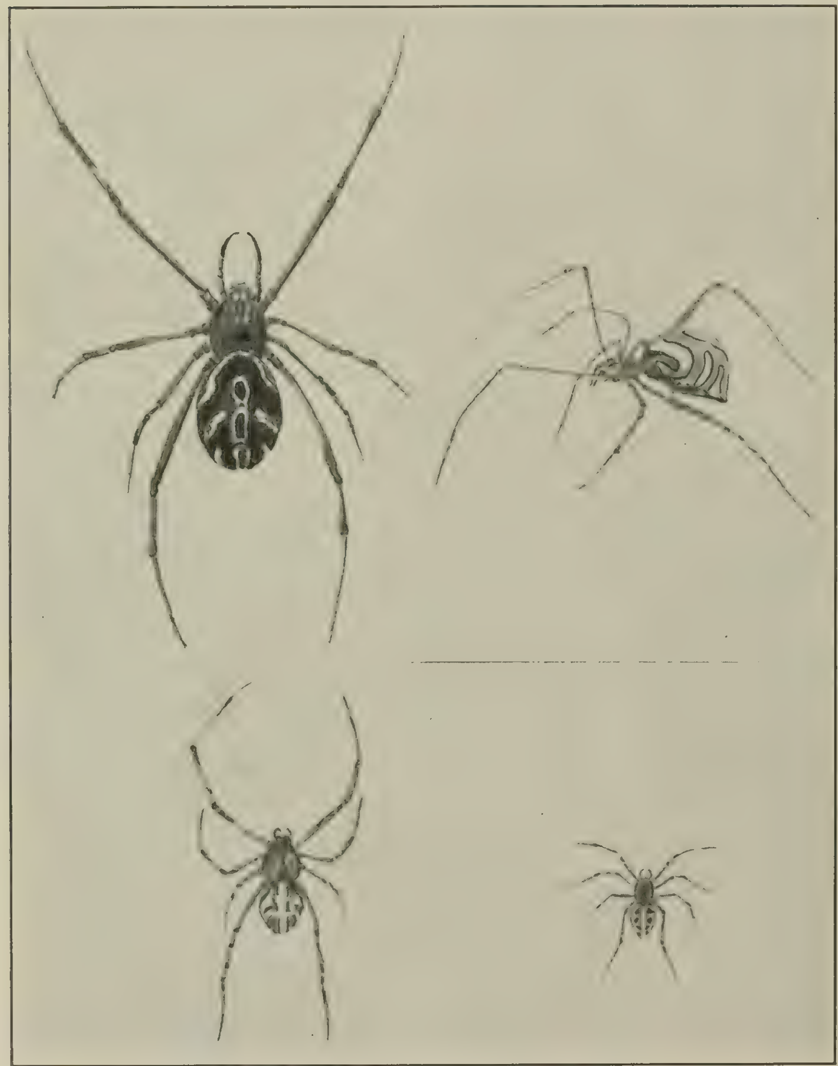
1927. Error of determination of toxicity. Proc. Roy. Soc., ser. B, vol. 101, p. 483.

Troise, E.

1928. Sérum actif contre le venin de l'araignée *Latrodectus mactans* C. R., Soc. Biol., vol. 99, p. 1434.

IMMATURE FEMALE TAKEN WITH RED FILTER SO AS TO SHOW THE HOURGLASS WHITE IN A BLACK-AND-WHITE PRINT.

In nature the hourglass is red and the rest of the spider is the black of polished ebony. The banded legs here are a sign of immaturity



FOUR STAGES IN THE DEVELOPMENT OF THE FEMALE.

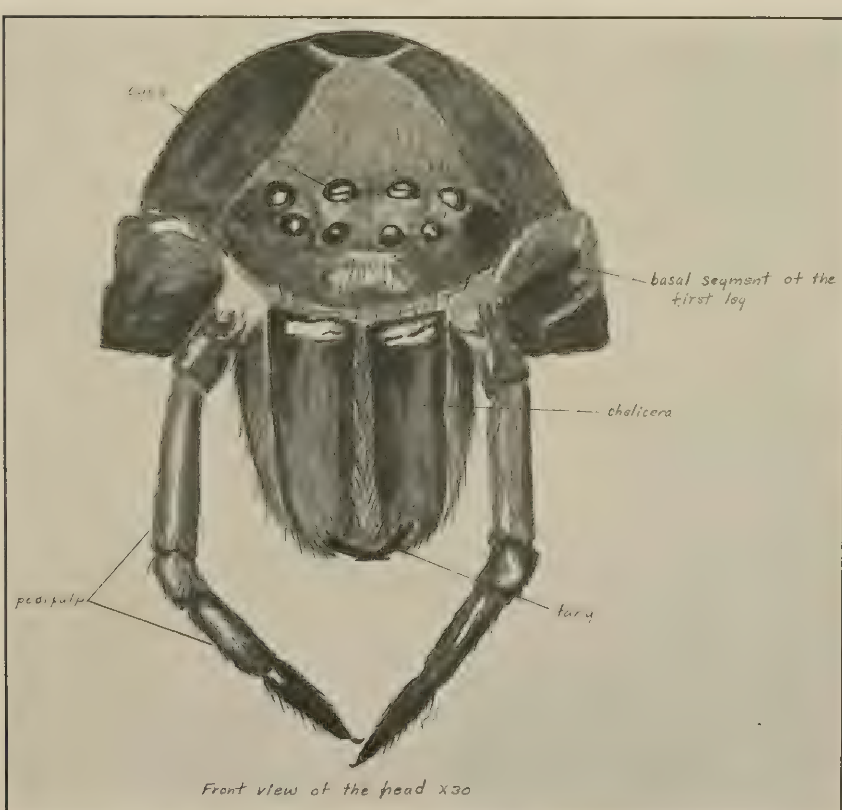
About two-molt intervals. The largest is about two molts removed from maturity, the smallest is the spider as it emerges from the egg sac. × 6.

1. BLACK WIDOW IN CHARACTERISTIC POSITION GUARDING HER EGG SAC.

2. THE EMERGENCE OF THE YOUNG SPIDERS FROM THE EGG SAC.

THE MALE, SHOWING THE WHITE MARKINGS ON THE BACK, THE LIGHT-COLORED AND BANDED LEGS, AND THE SWOLLEN GENITAL APPENDAGES OF THE PALPI.

1. PORTION OF A CROSS SECTION OF A POISON GLAND.



2. DIAGRAMMATIC, ANTERIOR VIEW OF HEAD, SHOWING CHELICERAE AND FANGS OF MATURE FEMALE.

THE LANGUAGE OF BEES [1]

By Prof. K. von Frisch
The University of Munich

To understand the language of bees it is first necessary to know something about the senses of bees. The senses of bees are of special interest for biologists, because bees are flower-visiting insects. Since the time of the German naturalist Chr. K. Sprengel, more than 140 years ago, we distinguish two main types of flower in the higher plants. A great many plants have small, scarcely visible blossoms without any scent, and their pollination is effected by the wind. Such blossoms have plenty of pollen, which is spread by the wind and comes by chance to other blossoms of the same species. The other plants have conspicuous, brightly colored blossoms, or a striking scent, or both colors and scent. We call them flowers. Such flowers produce honey, and they are therefore visited by feeding insects, which effect the pollination quickly and surely by flying from one flower to the next one of the kind. It seems probable that the flowers have their color and scent to make them more striking for the visitors. In this way, the insects can more easily find them and get their food, and the pollination of the flowers is guaranteed.

Sprengel's view was not accepted by all naturalists. There was a controversy on this subject for many years, especially concerning the function of the colors of flowers. Even 25 years ago Professor Hess asserted that bees and all other insects are color-blind. If this is true, the colors of flowers cannot be of the biological significance that Sprengel thought. I tried, therefore, to find out whether bees can distinguish colors.

The honey bee is a social insect. It lives in a beehive. In such a hive there are about 70,000 bees, only one of which is a fully developed female, the queen, the only egg-laying insect of all the inhabitants of a beehive. The males are plumper, and very stupid and lazy. Most of the inhabitants are worker bees. They are not able to produce eggs under normal circumstances. But they do all the work in the hive, they feed the larvae, they build the wax combs, they are the charwomen in the hive, and only the worker bees fly out to get honey and pollen as food for the inhabitants.

[1] Lecture delivered at University College, London, March 1937. Reprinted by permission from Science Progress, vol. 32, No. 125, July 1937.

Such food-collecting worker bees we take for our experiment. We use the scent of a little honey to attract some bees to our experimental table, and feed them, for instance on a blue cardboard. They suck up the food and, after homing, give it to other bees in the hive. Then they return to the good feeding-place they have discovered. We let them do so a while, and then we take away the blue cardboard with honey and put a new clean blue cardboard on the left, and a red one on the right of the feeding-place hitherto existing. Should the bees remember that they found the food on a blue cardboard, and should they be able to distinguish between blue and red, they would fly to the blue color. That is exactly what happens.

This is an old experiment, already carried out by the English naturalist John Lubbock. It proves that bees can distinguish colors. But it does not prove that bees have color-sense. It is not the same thing. There are (very rarely) totally color-blind men. They see all things in much the same manner as we see them in an ordinary photograph. They can distinguish between red and blue, for red is very dark to them and blue much lighter. From our experiment we cannot conclude whether the bees have distinguished red and blue by the colors or by the shades, as a color-blind man does.

For a color-blind human eye every color is a gray of a distinct degree of brightness. What the brightness may be for the eye of a color-blind insect we do not know. We therefore make the following arrangement.

We place a blue cardboard on a table and beside it and around it gray cardboards of all shades from white to black. On each card there is a little watch-glass, but only the glass dish on the blue cardboard contains food (sugar water). In this way we train the bees to the color blue. Bees have a very good memory for place. We therefore change the respective positions of the cards very often. But the food is always placed on the blue cardboard, and the color therefore indicates invariably where the food is to be found.

After some hours or after some days we can make the decisive experiment. The cardboards and glass dishes soiled by the bees are taken away. We put on the table a new, clean series of differently shaded gray cardboards, and anywhere between them we put a clean blue cardboard with an empty glass dish. The bees remember the blue color and alight only on the blue cardboard. They distinguish it without hesitation from all degrees of gray. They therefore have a color sense.

Training to orange, yellow, green, violet, or purple gives the same good results. But bees trained to scarlet red alight not only on the red paper but in the same manner on black and all dark papers in our arrangement. Red and dark are the same for bees' eyes. Bees are

red-blind. That is very interesting. We understand why scarlet red bee-blossoms are so rarely found. There are very many red flowers in America, for instance, but only in bird-blossoms. Birds' eyes are very sensitive to red. In Europe there are some plants with red flowers, but their pollination is—with few exceptions—effected by certain butterflies. These butterflies are the only insects which are not red-blind. There is an exception to the rule—the poppy, the flowers of which are visited by bees although they are scarlet red. But these flowers reflect many ultraviolet rays. Bees are able to perceive ultraviolet rays. Ultraviolet is a special color for them, distinguishable from blue and all other colors. It is evident that the colors of flowers have been developed as an adaptation to the color-sense of their visitors.

One more thing is of interest to biologists. We make the following experiment. We train bees to blue, and then we put all the different-colored cardboards on the table. The bees seek the blue color, but are unable to find it with certainty; they confuse it with violet and purple. Bees trained to yellow confuse the yellow with orange and green. It is important to notice that they cannot distinguish as many color shades as we can.

Bees restrict their visits to certain flowers. A given individual on its trip always visits definite species of flowers. That is of advantage for the bees, which on all flowers of the same kind meet with the same mechanism of blossom and save time through being acquainted with it; it is also of advantage for flowers, for their pollination depends on bees coming from other flowers of the same species. If the bees specialize in certain flowers, they must be able to distinguish the different kinds of flowers. Biologists formerly thought that it was the difference of color shade which enabled bees to distinguish them. Now we hear that bees cannot distinguish so many different shades of color as we can. They must, therefore, have other means of distinguishing the different kinds of flowers. It might possibly be the scent of flowers. Such considerations led me to my work about the sense of smell in bees

The result was that we found that the scent of flowers is the most important factor that enables bees to recognize the different flowers. We can train bees to scent just as we trained them to color. On a table we place some cardboard boxes, each of which can be opened from above. There is a hole in the front of the box. In only one of the cardboard boxes is there a feeding-glass, and into the same box we drop a little essential oil. The other boxes are without scent and without food. We change the position of the food box frequently in order to avoid a training to place. The scent guides the bees to the food. After some hours we put away all the boxes soiled by the visiting bees, and make a new arrangement with boxes not yet touched by bees. In one of them, we drop a little of the scent we have adopted for training

purposes, but there is no food in it. The bees fly to the boxes, smelling around the holes, but they only enter the scent box. It is therefore clear that they can smell this scent, and that they use it as a guide to the food place.

The sense of taste is a very closely allied sense. It is also a chemical sense. But for taste it is necessary that the mouth parts should come in contact with a solution. If it is a sweet solution, the bees suck it up. Indeed, the bees are rather fastidious about sweetness. If it is a solution containing 20 percent saccharose, they suck it up. If it contains 10 percent we can see that in bees as in men there is an individual difference in taste. Some bees drink, others hesitate, and others refuse it. If it contains 5 percent, they taste it and refuse to accept it. In this connection it is interesting that nectar in bee-blossoms is always a solution with a high content of sugar; on an average nectar contains about 40 percent sugar.

Training to taste is impossible. Either they drink the solution, or they refuse it. Nevertheless, it is possible to find out something about the quality of their sense of taste. But I cannot explain the methods in a few words. Let me only say that bees can distinguish the same qualities as we can—sweet, bitter, sour, salty. But not all substances we consider sweet are sweet for bees. Many sugars very sweet for us are tasteless to bees, e. g., lactose, cellobiose, raffinose, etc. And the artificial sugars saccharin and dulcin are not sweet but are tasteless to bees.

It is much easier to find out more facts about the quality of the sense of smell in bees, because we can train to a certain scent. Thus, for example, we provide all the boxes with different scents. The bees trained to a certain scent are able to pick out the training scent from 30 to 40 different scents. Furthermore, we can dilute the training scent more and more, and the result is that for the sense of smell in bees the limit is quite the same as for human beings. The scent of most flowers, therefore, cannot attract from a great distance. The color of flowers has the advantage of attracting bees from a greater distance. Scent has the advantage of being perfectly distinct for each species of flower. And so the scent permits the definite recognition of flowers from nearby.

In earlier times biologists thought that the function of the scent of flowers was to attract insects and to enable them to find the flowers. I think this is true of such bees as fly out to seek new feeding-places; for scout bees. Another function of scent is to enable the collecting bees to recognize certain flowers to which they are true and to distinguish them from other kinds of flowers. But there is one more function of scent—perhaps the most important. To explain it I must speak about the language of bees.

They have something like a language. That is clear from the following observation: When I want some bees for experiments, I place some sheets of paper smeared with honey on the experiment-table in the open air. Then I have to wait many hours, many days even, until finally a bee discovers the feeding-place. But as soon as one bee has found the honey, very many will appear, perhaps several hundred, within a short time. They all come from the same hive as the first discoverer. The latter must have announced its discovery at home. How is that possible? How could it communicate its discovery?

To clear up the matter two conditions must be fulfilled: First, a hive allowing one to watch all events taking place on the wax combs in the interior of the hive. For this I constructed observation hives in which the wax combs are not arranged one behind the other, but one beside the other, all together forming a large wax comb, the surface of which can be observed through glass windows. Second, every experimental bee must be numbered to enable it to be recognized personally at first sight in the mass of other bees on the wax combs. I succeeded in painting them with colored spots in five different colors. A white spot on the fore part of the thorax is number 1, a red spot 2, orange 3, yellow 4, green 5. A white spot on the hind part of the thorax is number 6, red 7, orange 8, yellow 9, green zero. Now it is possible to write two-figure numbers. The hundreds we paint on the abdomen. Thus we can number them up to 599. The colored numbers can be read as easily as written ones, and can be recognized when the bee is in flight, so that at our feeding-place we can see from a considerable distance—here comes No. 17, etc.

Now, a bee which has discovered the feeding-place is marked with color and observed after homing in the observation hive. First, it delivers the honey or sugar water, found and sucked up on our table, to other bees in the hive. Then it begins to dance. On the same spot it turns round and round in a circle with quick, tripping little steps, once to the right, once to the left, very vigorously, often half a minute or a full minute on the same spot. The dance is then often repeated on another spot. It is not possible to give a good description in mere words. The dance finishes just as suddenly as it began, the bee hurries to the hole of the hive and returns to the feeding-place.

The bees on the wax comb around the dancing bee become greatly excited by the dance, they trip behind the dancer, following all its turning movements. They turn their heads to it and keep their feelers as closely as possible to its body, and it is evident that they are highly interested. Suddenly one of the following bees and then another turns away, cleans its wings and antennae, and leaves the hive. Soon afterward these new bees appear at the food place.

After homing, they dance also and the more bees there are dancing in the hive the more appear at the feeding-place. It is clear that the existence of the food is communicated by the dance in the hive. But it is not clear how the bees which have been communicated with can find the feeding-place. How can they know where it is, and where they have to fly?

The simplest assumption would be that when the discoverer returns to the feeding-place the new bees fly behind it. But that is not the case. The new bees do not fly behind our marked discoverer; they appear at the feeding-place quite independently.

I could not understand it till I made the following experiment: I fed some of the numbered bees of the observation hive at a feeding-place 40 feet to the west of the hive. In the meadow round the hive to the north, south, west, and east I put glass dishes with sugar water and a little honey on the ground. If the dancer bee dancing in the hive reported where the feeding-place was, the new bees would all fly to the west feeding-place. As a matter of fact, a few minutes after the commencement of the dance new bees appeared at the same time at all the little dishes to the north and south, to the west and east. They did not know where the food was. They flew out in all directions and looked for it. When there were no dances in the hive, the little glass dishes in the meadow were not visited by any bee for many days. As soon as there were dances in the hive, the dishes in the neighborhood were all found within the shortest time.

But not only in the neighborhood! In further experiments I left the feeding-dish, visited by some numbered bees, at a short distance from the hive. And I put some other dishes farther and farther away in the meadow, observing whether they would be found or not. The farther they were the longer time it took till they were found by the bees sent out by the dancer. In the last experiment they were found after 4 hours in a meadow a full kilometer from the hive, with hills and woods lying between them. It is clear from a long series of experiments that after the commencement of the dances the bees first seek in the neighborhood, and then go farther away, and finally search the whole flying district.

So the language of bees seemed to be very simple. But feeding from glass dishes is not natural for bees. If we make the conditions more natural, we get a new riddle at once.

We put the glass dish away, and feed the numbered bees at the same place on flowers, e. g., on cyclamen. Into the flowers we drop sugar water to provide plenty of food. The collecting bees dance after homing. New bees fly out seeking—but seeking something definite. In the vicinity we put a larger dish with cyclamen on the ground, and a similar dish with phlox. The new bees are only

interested in cyclamen. They take no notice of phlox. Now we change the flowers at the feeding-place and put food in phlox blossoms. After 5 or 10 minutes the situation at the observation place changes, the new bees now are not interested in cyclamen, they only alight on phlox and search through the flowers, examining them as if they were convinced there must be food there. Everywhere in neighboring gardens where phlox plants are we can observe questing bees—a curious sight for everybody aware that bees cannot get honey from phlox blossoms and therefore never visit phlox under normal circumstances. The dancer bee has not only reported that there is food, but also in what kind of flowers it is to be found.

In performing this experiment I succeeded with all kinds of flowers with the exception of flowers without any scent. And so it is not difficult to find out the manner of communication. When the collecting bee alights on the scented flowers to suck up the food, the scent of the flower is taken up by its body-surface and hairs, and when it dances after homing the interested bees following the movements of the dancer bee, and holding their antennae against its body, perceive the specific scent on its body and know what kind of scent must be sought to find the good feeding-place announced by the dancing bee. That this view is correct can be proved easily. We feed some numbered bees, giving them sugar water in a glass dish, on a cardboard on which some essential oil has been dropped. Then, in the neighborhood on the ground, we put some cardboards with drops of various essential oils on them. The bees sent out by our dancer bees are only interested in the scent of the essential oil dropped on the feeding-cardboard, and alight on every place and everything provided with this scent. They take no notice of cardboards provided with other essential oils.

It is thus seen that there is a biological function of flower scent not known before. The dancing bee can communicate a message about all kinds of scented flowers by means of the scent adhering to its body.

But the language of bees is still more perfect than has been shown up to now. A little variation of our experiment makes this clear. At the feeding-place we put sugar water in the glass dish, and we renew all sugar water taken away by the collecting bees. There is plenty of food. The collecting bees dance after homing, and new bees continually come out, and more and more discover the feeding-place. Now we remove the full glass dish and we put in its place a glass dish provided with some sheets of filter paper moistened from beneath with a little sugar water by means of a syringe. Now there is a scarcity of food. It is troublesome to suck it up, and takes a long time. Now the bees do not dance after homing. They deliver the food to other bees and return to the feeding-place, they continue to collect the food no less industriously, but they do not dance, and so

they do not attract new worker bees to their feeding-place. Just the same is true of flower-visiting bees. They only dance if they find plenty of food. As soon as the flowers are visited by so many bees that all nectar produced by the flowers can be easily collected and taken away, there is no longer plenty of food, the dances stop, and no more worker bees are attracted. This makes it possible that there is always a correct proportion between the number of collecting bees and the quantity of food offered by a certain kind of flowers.

But one more thing still—the dances depend not only on the quantity of food but also on its sweetness. If we feed the bees with sugar water of a very high concentration the dances are very vigorous. If the concentration is diminished, the dances are continued, but less vigorously. If the concentration is still further diminished to a certain point, the collection of food is still continued, but there are no dances in the hive, although there is plenty of food. In natural conditions this is very important. For when various kinds of flowers with different concentrations of nectar begin to bloom at the same time, and are discovered by scout bees belonging to the same hive, the bees discovering the flowers with the best nectar dance most vigorously, and attract the largest number of worker bees for the best flowers. That is the role of the sense of taste in the language of bees.

But there is a word in the bee language not yet mentioned. The bees have a scent organ on their abdomen located in a pocket of skin containing glands. Usually the scent organ is closed and cannot give out scent. But bees which have discovered a good feeding-place put out the scent organ on returning to the place, and thus they give out a scent that is very attractive to other bees. It can be concluded from special experiments that the scent of this scent organ is much more intensive for bees than for us. It tells the questing bees with special emphasis where the good place is, as soon as they are in the vicinity, and attracts them from quite a considerable distance.

It may be that some of my statements seem to be a little hypothetical. But all the results I have mentioned have been obtained from long series of experiments. To deal more thoroughly with the experimental methods here is impossible.

To sum up: If a new kind of flower begins to bloom in a certain region, it is discovered after some time by scout bees. The first bees find the flowers full of nectar. They find plenty of food and after homing they report the discovery by dancing, and in addition indicate the species of flowers by means of the scent adhering to their bodies. The bees communicated with fly out and look for the flowers with this specific scent. Flying out in all directions, they find out in the shortest time the plant which has commenced to bloom, wherever it is in the entire flying district. Where there are already collecting bees, the scent of the scent organ makes it easier for fresh

questing bees to find the good feeding-place. When the number of bees has become sufficient to collect the amount of nectar in these flowers, the flowers are no longer full of nectar, the nectar becomes scarce, there is no more dancing and the number of bees does not increase. If different plants begin to bloom at the same time, the flowers with the sweetest nectar cause the most vigorous dancing and, incited by the scent adhering to the body of the dancer bee, the largest number of bees fly to the best feeding-plants.

FOREST GENETICS[1]

By Lloyd Austin
In Charge, Institute of Forest Genetics, Placerville, Calif.

[With three plates]

The widespread interest in conservation and reforestation throughout the nation today is focusing attention more and more upon the need for improved strains of forest trees. People are awakening to the realization that the commonly used forms of even the best species of existing timber trees are, in most instances, comparatively ill-adapted to planting under present economic conditions.

Is it not too much to expect that the wild types of trees as found in nature would be ideally adapted to meet the exacting demands of the present day? Centuries ago the agriculturists realized the inadequacy of wild plants and animals and began their efforts to develop superior strains. Today, after an extended period of breeding and selection by innumerable individuals and organizations, there are available for the use of modern farmers a great many improved types of farm crops, orchard fruits, and domestic animals. Most of the original wild types have long been abandoned for economic production.

It is little short of amazing then, that at this same period of development almost all reforestation activities are seriously encumbered, and rendered only partially effective, by the fact that they must, of necessity, utilize the wild, primeval types of forest trees that have not been improved from those that were available when the white man first trod upon American soil.

Why such a paradoxical situation? There are probably two fundamental causes. In the first place, so long as there was an abundance of virgin timber, forestry was, to a considerable extent, merely a matter of protecting, harvesting, and marketing nature's accumulation of centuries. But now that man must take an active part in restocking the vast areas of denuded land, timber must be regarded as a crop, and as such falls naturally and properly within the domain of the plant breeder or geneticist. Secondly, it seems likely that the great longevity of timber trees, and the infinite com-

[1] Reprinted by permission from American Forests, vol. 43, No. 9, September 1937.

plexity of the problem, have, until recently, deterred foresters and geneticists from giving detailed thought to the wonderful and stimulating possibilities of specializing in this particular field of research.

In 1924, there was no institution in the United States, and probably none in the entire world, devoted solely to the production of inherently superior rapid-growing strains of forest trees. But in 1925, through the extraordinary vision and foresight of James G. Eddy, a lumberman of Medina, Wash., the Institute of Forest Genetics was founded at Placerville, Calif. Mr. Eddy's knowledge of the practical aspects of forestry and his studies of plant-breeding achievements led him to the conviction that the improvement of the wild strains of timber trees is both necessary and feasible—a conviction that has since been abundantly confirmed.

Many have thought that the genetical principles of selection and hybridization could be applied to forest trees, but no other American took steps to actually establish an institution devoted solely to that purpose. His never-ending enthusiasm, his stimulating counsel, and his personal support of the entire investigative program for the first 8 years, have made possible the progress that has been made.

As the research in this virgin field has progressed, and as its aims and purpose have gradually broadened to meet the needs of the nation, there has been a natural and corresponding broadening of the organization of the Institute. In 1932 the original name, the Eddy Tree Breeding Station, was changed to the Institute of Forest Genetics, better to express the broad and scientific character of the investigations being conducted. At that time the property and control were transferred to a national Board of Trustees of 18 prominent scientists and business men well qualified to guide the destinies of such an institution.

During 1933 and 1934 the Carnegie Institution of Washington made several grants to the Institute to aid in carrying forward its protracted research work. Shortly after this the United States Bureau of Plant Industry, and later the Soil Conservation Service, helped substantially in financing the investigations which have a close connection with the expanding program for erosion control. The United States Forest Service also assisted materially during this period.

Another important and auspicious step in the organization of the Institute took place during the latter part of 1935. As a result of the efforts of the Trustees and other friends of the Institute over a period of several years, the plans to join this national work for public benefit with the research work of the United States Forest Service were made possible by an initial Congressional appropriation of $50,000 specifically for the genetical work of the Institute. Although the Institute of Forest Genetics is now affiliated with the California Forest Experiment Station of the Forest Service, the investigative work will retain

its national character and scope. The Board of Trustees is being continued as an Advisory Board.

Placerville, Calif., was chosen as the site for the Institute's main experimental station because of an unusual combination of favorable conditions. It lies in the center of the belt containing the finest stands of the principal western pine, ponderosa pine. Within the confines of the State of California can be found more species of pines, on which the Institute is specializing, than grow wild in any area of similar size in the world.

Climatic conditions are naturally of fundamental importance in determining a suitable location for an enterprise of this character. The average growing season to date at the Institute is 237 days. The lowest temperature ever recorded is 16° Farenheit, which is comparable to central Florida. The location chosen is one of the few in the entire United States that is situated in an important forested area and that has a climate sufficiently mild to permit assembling large collections of basic tree-breeding material from nearly all parts of the world, as is successfully being done at the Institute.

Although the climate at the main experimental station itself is quite moderate, there is abundant opportunity, within a driving distance of 50 miles, to obtain testing areas in the foothills and higher reaches of the Sierra where minimum temperatures range from 16° above zero to 30° below. On the Atlantic Seaboard one would have to travel about a thousand miles, from central Florida to New England, to find an equal range in minimum temperatures.

During the 10 years since its founding the Institute has uncovered many encouraging facts that indicate clearly that forest genetics is not only entirely feasible, but that it will yield usable results in a much shorter time than had been anticipated. Some of the very factors that are ordinarily regarded as serious obstacles to progress have been overcome and have been turned about so that they now serve as material aids to the tree breeder. For example, the long life of timber trees was regarded by many as a factor that made it seem likely that it would be at least several decades before tree breeders could offer to forest planters seeds of improved new types in sufficient quantities to be of practical significance in reforestation. Yet a short-cut method has been devised that makes it possible in a relatively few years to isolate from among the innumerable strains of a given species that nature has produced through countless generations, those with superior germ plasm—that is, those that have the inherent characteristics most desired by present-day planters.

The process used is known as a Progeny Test and it isolates these superior, most vigorous strains as individual seed-trees in the forest, based on well-replicated nursery and plantation tests of their

114728—39——29

progenies. The very fact that timber trees are longer lived than agricultural crops is a distinct advantage, for it makes possible a long-continued supply of better seeds once the desirable seed-trees are found. Many of these superior trees that are being discovered as the investigations progress have been growing for 100 years or more, and are capable of yielding for many decades heavy seed crops every few years. Even a single seed crop from one of these selected seed-trees will often be such that enough seed can be collected to produce from 5,000 to 20,000 superior seedlings. This illustrates the untold potentialities of these new genetical methods, and the comparatively short time required for them to yield results that have practical application to present-day reforestation.

Results so far seem to indicate that the easily obtained wind-pollinated seed is usually adequate for the various preliminary tests in which seed is gathered over wide areas, even though only one parent is thus known and controlled. However, as the investigations become localized in the areas that are found to contain the better trees, it may prove desirable to conduct some of the progeny tests with self-pollinated seed. Also, various tests of crossing the better individuals will be helpful in showing which combinations of parents will yield the best offspring.

As rapidly as relatively isolated plots of native trees containing a number of germinally superior individuals are found, it would seem that in preparing them to serve as future seed supply areas, it may be possible to improve the average vigor of the offspring from the best trees still further by cutting out, not those that appear externally to be undesirable, but those trees that the progeny tests have shown to be inferior. Thus their pollen will be eliminated and henceforth natural cross pollination will take place largely between the hereditarily better types.

The application of this progeny test method over a wide range of seed sources has not only pointed out some of the best individual seed-trees in each locality, but it has also brought to light marked differences in the general character of the numerous local strains. In one such test with ponderosa pine, the Institute compared side by side in a single nursery the progenies of 765 individual seed-trees growing in 60 counties in 12 western States and in British Columbia. The data gathered from this exhaustive study revealed the existence of numerous geographical races of this important timber species, each with distinct physical characteristics that will affect both the volume and quality of the lumber produced. One of the most significant and useful of the facts that these tests have revealed is that, in the Sierra Nevada of California, hereditary vigor has been found to be quite generally associated with the lower elevation of the seed source.

Although these and other findings here reported will, obviously, need checking by further experimentation, enough has been learned to demonstrate the tremendous practical possibilities that these methods offer to whomsoever will put them into use.

There probably will be no one best strain of any one species of pine for all timber-growing climates and soils where the species is to be used. Various superior strains will be needed, and as these are gradually developed and widely tested, they can be expected to exhibit some variation in the expression of their hereditary characters in different localities, depending on the local environmental conditions. Consequently, various field trials will be required to determine just which of the better strains are best adapted to each locality. In this way we will insure the maximum growth and highest quality of lumber possible under each set of conditions.

From still another line of experimentation has come valuable new information that demonstrates the practicability of improving the strains of forest trees within a reasonable length of time. Many had thought that it would usually be necessary to wait until seedlings were 15 to 20 years old or more before they would flower so that hybridization experiments could be conducted with artificially grown trees. But tests in the Institute's nursery and arboretum have shown that many different species of conifers, particularly pines, flower at the early ages of 2 to 5 years.

Astonishing as it may seem, one Chinese species of pine, *Pinus sinensis*, actually blossomed profusely in the nursery at the age of 1 year from seed, thus causing pine breeding to approach, in some respects, the facility with which annual crops, such as wheat and corn, can be hybridized. As early as 1932 no less than 44 species of forest trees were flowering in the Institute's arboretum, although the first plantings were made only 6 years before, and many of the trees were considerably younger than this. Among those that flowered at this early date were several 2-year-old seedlings of the Japanese red pine, *Pinus densiflora*, grown from seed collected in the arboretum. Not many species are quite as precocious as this, but the average age of initial flowering for pines has been found to be so low that cross pollination experiments can be conducted with them and tree generations can be secured much more rapidly than had been anticipated.

Another discovery offering much encouragement to the pine breeder is the great longevity of pine pollen. Simple and inexpensive methods have been found that will often keep this pollen viable for a year or more. This is in sharp contrast to the condition that exists in some other plants, such as corn, in which the pollen lives only about 24 hours, and if not used within that time is of no avail. The long life of pine pollen makes possible its shipment from the forests of distant

countries for hybridization with native species and with others that may be flowering in the arboretum.

The possibility of hybridizing forest trees, and of actually combining in a single new hybrid form the desirable characters previously existing only in separate species, has been fully demonstrated in hybrids produced at the Institute, as well as in certain natural hybrids that have been discovered. The most outstanding of the Institute's artificial hybrids to date is a cross of the Knobcone pine, *Pinus attenuata*, a relatively slow-growing but hardy species, and the Monterey pine, *Pinus radiata*, a species which lacks hardiness but which is the fastest-growing of all species tested from 40 countries. All of the hybrids have, very fortunately, inherited the cold-hardiness of the seed-parent and the rapid growth of the pollen-parent.

As one of the results of the study of artificially controlled pollination of pines, it has been observed in experiments with several different species that when the flowers of a pine tree are pollinated with pollen from the same tree, the yield of seed tends to be abnormally low, and the germination of the seeds is usually comparatively poor. In addition, the resultant seedlings are often quite deficient in vigor, as compared with normal seedlings resulting from wind-pollination, which ordinarily seems to include much crossing with neighboring trees. These results may be taken as indications that, in all probability, many of the individual trees in the wilds are partially self-sterile and will yield vigorous offspring only when cross-pollinated with pollen from other trees, usually of the same species.

Apparently pines behave much as do many of the crop plants, such as corn, that have been under tests by geneticists for decades. It is a common experience in plant breeding to find that there is a reduction in vigor following selfing or inbreeding, particularly in the first generation. One application of this finding in practical forestry is to avoid the collection of seeds from individual trees that are comparatively isolated, since such seeds are probably mostly self-pollinated. Also, in choosing seed-trees to be saved in logging operations, the desirable practice, judging from present knowledge, would seem to be to leave them in small groups; or if left singly, the seed trees should be left close enough together to insure adequate cross-pollination by the wind.

It is well recognized that hybrids between species often will not come true when reproduced by seed. Consequently the Institute has given some attention to the possibility of reproducing pines by budding and grafting, which are the usual commercial methods of propagating practically all orchard fruits and many ornamentals, in order to insure trueness to type. Though these methods of reproducing pines are still in the experimental stage, the preliminary tests of

budding and grafting were quite successful, even when one species was budded onto another.

The more one studies genetics, the more thoroughly he becomes convinced of the widespread application of the fundamental laws of heredity, and the importance of giving thought today to the generations yet to come. The universality of these considerations may be appreciated by observing the close similarity in the situation that has long existed in forestry and in human society. When war is declared, the best specimens of manhood are sought out and sent to the front, often never to return, while those that the examinations show to be unfit, are left at home to perpetuate the race.

With timber trees, too, this unfortunate practice has been all too prevalent of using the best for present needs and leaving the discards with their inferior heritage for the future—a tragic policy, bringing about the deterioration of the strains of our forest trees through what might well be termed "the perpetuation of the unfit." In some ways it may seem only natural that many have yielded to the pecuniary temptation to send to the mill all the finest and largest specimens, with straightest grain and the best form, leaving as seed-trees for natural regeneration only the misshapen, diseased, and otherwise undesirable types that are not fit for lumber. In many cases the seed gathered for artificial reforestation has been little better, for all too often the collectors' chief concern has been ease of gathering, and hence much of the seed has come from low, scrubby or stunted trees.

We know that not all of these poor-appearing trees have an inferior heredity, for those defects that are caused by environmental influences, such as mechanical injuries, are in no respect hereditary. Yet on the other hand, we also know that many visible characteristics that are undesirable economically, such as spiral grain and susceptibility to disease, and many others, are often definitely hereditary. It seems obvious, then, that any system of selection in which only the culls and poorest specimens are saved for reproduction must lead inevitably to the deterioration of the strain.

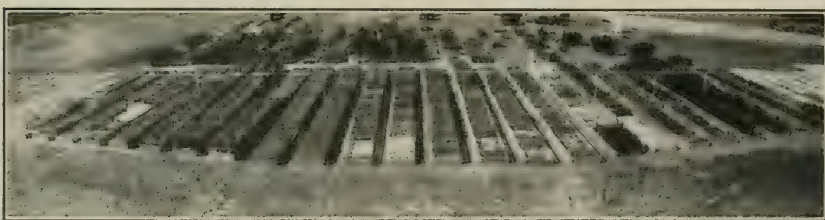
Another example of the unfortunate tendency to destroy the best, and one that is seldom appreciated, is afforded by the Institute's previously-mentioned discovery that the forms of ponderosa pine having the greatest inherent vigor seem to come from the low elevations in the Sierra of California. In this belt, at an elevation of only 900 feet above the sea, lies Coloma, where gold was discovered in 1848, starting an avalanche of adventurous prospectors to California. With surprising rapidity, mining camps sprang up all along the foothills, and as this new western civilization developed, man unwittingly logged off great quantities of the easily-accessible low-altitude trees that we now find constitute a strain having exceptional growth capacities. This deforestation has been carried still farther by the fires that

are now so prevalent in this zone. At present there remain in this low-elevation belt only scattered remnants of the extensive forests that existed prior to the advent of the white man. This slow but inevitable utilization and destruction of the relatively few remaining low-elevation trees of superior heredity is still going on, and so it behooves us to test as rapidly as possible the offspring of such of these trees as still exist. For, while nearly all the trees of this strain seem to yield relatively vigorous progenies, among them may be found one that surpasses all others—the progenitor of a new, rapid-growing race of ponderosa pine that can be grown on very short rotations.

It is because forest genetics has often been regarded as an exceedingly slow and unpromising line of scientific endeavor that I have purposely summarized in this article some of the Institute's results that point strongly in the opposite direction. It is not the intention, however, to give the impression that the path of the tree breeder is strewn with thornless roses. His advances are always beset with difficulties, only a portion of which have as yet been overcome. Nevertheless, if we may be permitted to judge the future by the accomplishments of the past, the prospects from our present vantage point are very bright for bringing about, through the use of genetics, major advancements in American forestry.

A TREE BREEDER AT WORK.

1. Where interesting experiments in speeding up the production and development of trees are being made—the arboretum of the Institute of Forest Genetics in the Sierra Nevada foothills.



2. Three yearly nursery section panorama—right, enclosed frames for 1-year-old "Progeny Test" and hybridizing experiments; foreground, 2-year-old "Species Test" beds, and in the background are seen remnants of the results of the 3-year-old experimental nursery.

3. Administration Building and the Institute's headquarters.

1. One of the Institute's fastest growing trees—this Monterey pine has shown an average growth of over 4 feet a year for 5 years.

2. A Japanese black pine has flowered thus abundantly at 4 years of age from seed.

THE STORY OF THE MAIDENHAIR TREE[1]

By Sir Albert C. Seward, Sc. D., F. R. S.

INTRODUCTORY

In March 1936 several letters were published in The Times drawing attention to the remarkable history of the maidenhair tree (*Ginkgo biloba* L.) and its unique position as a link between the present age and an almost incredibly remote past. The interest awakened by the correspondence suggested to me the possibility that a fuller account of the history, both of the maidenhair tree itself and the family or group of which it is the sole survivor, might be acceptable to readers of Science Progress. *Ginkgo* was selected as one of several examples of living plants of ancient lineage in a book first published in 1911 entitled "Links with the Past in the Plant World" and further reference was made to it in an article contributed to this journal in October 1935 on "Selections from the Study of Plant Migrations Revealed by Fossils." More recently, in an article published in Nature (May 1, 1937) attention was called to some important contributions to the geological history of the *Ginkgo* family by Dr. Florin of Stockholm and Professor Harris of Reading. My present aim is to give a fuller account of the story of *Ginkgo* and its allies, a story founded on data collected from plant-bearing rocks of many ages and from widely scattered regions. Evidence furnished by fossils enables us to state with confidence that the *Ginkgo* group of trees—the Ginkgoales—was once almost world-wide in its distribution and comprised many genera and species: a few million years ago this section of the plant kingdom fell from its high estate and is now represented by a single species. An attempt is made in the following pages, omitting unnecessary detail and technicalities, to present some of the evidence. The first part of this article is devoted to *Ginkgo biloba*, and closely related trees of the same genus which failed to persist until the present age. In the second part a short account is given of other genera included in the *Ginkgo* group that have long been extinct.

[1] Reprinted by permission from Science Progress, vol. 32, No. 127, January 1938.

PART I

GINKGO BILOBA

Ginkgo, like the larch, is one of the few naked-seeded (Gymnosperm) trees that is deciduous; it reaches well over a hundred feet in height: the branches are spreading or steeply ascending. In the autumn the leaves assume an attractive golden color before falling. In shape and venation the foliage is unlike that of any other tree; it is fan-shaped or triangular and varies considerably in size and shape. The specific name *biloba* was chosen because in many, though by no means all, leaves the blade is divided by a median V-shaped depression into two symmetrical halves. Leaves vary from about 1 inch to 2 or 3 inches in depth, and from 1 to 3 inches in breadth; they may reach a breadth of 6 inches, but this is exceptional. The slender leaf-stalk is 1½ or as much as 2 inches long. The lower margin of the blade may be almost straight and at right-angles to the stalk, or not infrequently in small leaves the outline is triangular, the two sides converging to the base: occasionally the lower margin has the form of a double ogee curve. The upper edge is rounded, entire, irregularly undulate, or bilobed. In some leaves, especially those on vigorous young shoots, the blade is often dissected by V-shaped depressions into four or more wedge-shaped segments. The deeply cut leaves with several cuneate lobes are reminiscent of the foliage of many extinct species. The range in size and shape of the foliage of the living species adds considerably to the difficulty of deciding whether or not certain fossil leaves should be regarded as specifically identical with *Ginkgo biloba,* or indeed one with another. Accurate comparison is impossible without the aid of supplementary evidence from structural features. Forked veins radiate through the leaf from the lower margin: the venation is very similar to that of the leaflets of a maidenhair fern (*Adiantum*). Two strands of conducting tissue pass from the stem up the leaf-stalk and branches from them form the spreading and forked veins. Here and there between the veins short tracts of secretory cells are easily recognizable as translucent patches when a leaf is seen in transmitted light, or as dark patches by reflected light. Similar secretory tracts are an almost constant character in the fossil leaves.

The leaves are borne on two kinds of shoot: long shoots which grow with relative rapidity and determine the shape of the tree; also short and very slow-growing shoots. On long shoots the leaves are scattered and spirally disposed, while on the short shoots about six or fewer are borne as a cluster at the tip. The surface of a dwarf or short shoot is covered with crowded scars left by leaves of past years. Special attention is called to the short foliage-shoots because they

are characteristic of many extinct members of the family; they are similar to the dwarf shoots of larches and cedars (*Cedrus*), and to the deciduous and smaller shoots of pines.

Male and female reproductive organs are borne on separate trees. It is possible to obtain both kinds of "flower" on one tree by grafting a female branch on to a male tree: this operation was successfully performed some years ago on the large male tree at Kew. My friend, the Rev. Prof. A. C. Moule of Cambridge, tells me that he discovered a passage in an old Chinese book advising the planting of male and female seeds close together in order to ensure fertilization at a later stage. This implies an uncanny power of distinguishing male from female even in the seeds. The male flowers—as it is convenient to call the reproductive shoots—are loose catkins bearing on a slender axis several short stamens, each of which has two or rarely three or even four pollen-sacs. The female shoots are longer and larger, each usually bearing a pair of ovules which develop into fleshy yellow seeds as large as cherries. In the Far East the maidenhair tree is spoken of as the silver apricot. Within the fleshy covering a hard shell, generally with a prominent median keel, encloses and protects the embryo and the store of food prepared by parent for offspring. The kernel (embryo and food) is eaten in China and Japan as a delicacy: the outer flesh is nauseous.

Ginkgo, despite the difference in foliage, was formerly included with the yew (*Taxus*) in the Taxineae, one of the families in another group of naked-seeded trees, the conifers. About 40 years ago a Japanese botanist, Hirase, discovered that the sperms are free-swimming bodies of relatively gigantic size, provided with innumerable lashing cilia in marked contrast to the passive and microscopically minute male nuclei of conifers. In view of this fundamental peculiarity, and having regard to other characters not found in conifers, a new family and a new group, the Ginkgoales, were instituted for this isolated, aberrant, and primitive genus of naked-seeded plants. Thus *Ginkgo* came to be regarded as the single representative not only of a genus and family but of a group of Gymnosperms. There are many interesting points connected with the structure of the seed and other technical questions which need not be discussed as they have no direct bearing on the more general considerations with which this article is concerned. *Ginkgo* resembles conifers in the main structural features of the wood; it is indeed very difficult to decide whether or not some examples of petrified fossil wood should be assigned to the *Ginkgo* family or to the conifers.

THE PRESENT HOME OF GINKGO

Some botanists believe that the maidenhair tree is still living as a wild tree in certain Chinese forests; others are definitely of opinion

that it exists only in cultivation, the apparently wild trees being the offspring of parents planted by man. One thing is certain: *Ginkgo* has long been cultivated in China and Japan, and the oldest specimens occur in the neighborhood of temples, so that it has sometimes been regarded as a sacred tree. Seeds have doubtless been dispersed by natural agency, producing trees at increasing distances from the parents: it is therefore not always easy to distinguish cultivated from wild specimens. English botanists and plant collectors who have traveled extensively in China say that they failed to discover the tree in forests remote from civilization. On the other hand, a few years ago a Chinese botanist recorded the occurrence of *Ginkgo biloba* in certain localities in the Chekiang province of eastern China: he wrote—"This tree is very common in Tienmu-Shan growing in association with conifers and broad-leaved trees. It seems to grow spontaneously in that region." An affirmative reply to the question, does *Ginkgo* still exist in natural forests as a wild tree? cannot be given with absolute certainty. It may still exist in places where man has played no part, and that is as much as can be said without reservation. There can be no doubt that China was the last, if it is not the present, natural home of the maidenhair tree. It was brought to Europe in the early part of the eighteenth century; to Utrecht about 1730, and to England a little later: the tree is now fairly common in European gardens, admired for its autumn coloring and the fernlike venation of the leaves. There is, however, another attribute which entitles it to our respect and protection: it is a remarkable and almost unique example of the extraordinary conservation and vitality through millions of years of a member of the plant kingdom whose forbears were forest trees ages before the birth of the human race, ages before the existence of our familiar broad-leaved trees, and antedating almost the whole of the mammals. In comparison with most impressive man-made monuments, such as the step pyramid of Saqqara, which take us back to the dawn of civilization, the records of plants preserved by nature in the sands and muds of former ages speak to us of a past beyond the power of human intelligence to appreciate. After reading the following summary of the history of *Ginkgo* and its allies it will be easier to appreciate the reasonableness of describing the maidenhair tree as one of the wonders of the world; it has persisted with little change until the present through a long succession of ages when the earth was inhabited by animals and plants for the most part far removed, in kind as in time, from their living descendants. *Ginkgo* is one of a small company of living plants which illustrates continuity and exceptional power of endurance in a changing world. The ginkgos that grew in western and eastern forests 100 and 200 million years ago were no doubt very similar in appearance to the species that alone survives; they lived the same life, depending upon the light of the

sun, the carbon-giving gas in the atmosphere, and the water in the soil exactly as trees of the present day. When we reconstruct the continents over which the forests spread and restore to life the contemporary companions of the old ginkgos, continuity gives place to discontinuity; land where there is now water and water over regions that are now land. As the wind spreads a kaleidoscopic pattern of lights and shadows over the massed branches of the tree, we cannot but be conscious of the contrast between the wind, that has blown since the earth began, and the varying nature of the old-time forests—

'Tis the old wind in the old anger
But then it threshed another wood.

When we regard the earth's surface in terms of the ordinary time-scale it gives us an impression of stability: adopting the time-scale of geologists we are able to measure the duration of earlier periods; as we pass from one age to another we can follow the shifting boundaries of continents and seas. With minds prepared by thoughts derived from a geological retrospect *Ginkgo* becomes much more to us than a mere tree; it speaks to us as an oracle recording in the trembling accents of its fluttering leaves the varying fortunes of its race and wanderings over the world's surface as age succeeded age; it gives us glimpses of the great procession of life and the building of the world in which we live.

A NOTE ON THE NAME GINKGO

The name *Ginkgo* was coined by Kaempfer, who traveled widely in the Far East, for a tree he first saw in Japan in 1690. In 1712 in his book Amoenitates Exoticae, he spoke of the tree as "Ginkgo vel Gin an, vulgó Itsjo, arbor nucifera folio Adianto," and published an excellent drawing of foliage-shoots and seeds. Linnaeus in 1771 adopted Kaempfer's generic name and called the plant *Ginkgo biloba.* In obedience to the rules of nomenclature governing botanical usage this is generally accepted. Twenty-six years later J. E. Smith proposed to substitute the generic name *Salisburia* for the "equally uncouth and barbarous" *Ginkgo* of Kaempfer; he also altered the specific name *biloba* to *adiantifolia.* Smith's proposal was made subsequent to the date accepted as the starting-point of botanical nomenclature and was therefore not adopted. The word *Ginkgo,* which The Times newspaper, in recent correspondence on the tree, preferred to spell Gingko, has been variously interpreted. In order to ascertain its true meaning I consulted my friend, the Rev. Dr. A. C. Moule, professor of Chinese at Cambridge, who at once became interested and spared no pains to satisfy my curiosity. His extended researches have now been summarized in a paper published in T'oung Pao, vol. 33, livr. 2 (E. J. Brill, Leiden).

The word *Gin* in Chinese means "silver" and Kaempfer thought that *Ginkgo* meant silver apricot. Professor Moule points out that there are no grounds for the termination *kgo;* the *g* cannot be explained and may be a slip in transcription, or *Ginkgo* may be a misprint for *Sankyo*, a word found by Professor Moule in one of Kaempfer's MSS. in the British Museum Library; it means hill apricot. The list of Japanese names which Kaempfer thought he was reproducing contains no such name as either *Ginkyo* or *Ginkgo*. The latter, Professor Moule writes, "is unpronounceable and probably ought never to have existed." But whatever the explanation of "*Ginkgo*" may be, the Japanese actually call the tree *Icho* (or *Itsio*) and the fruit ginnan, and it is clear from Kaempfer's MSS. that he was well aware of this. For a full discussion of all the names readers should consult the authoritative paper on "The name *Ginkgo biloba*" in T'oung Pao (vol. 33, livr. 3).

[I am also indebted to Professor Moule for much interesting information gathered from Chinese and Japanese writings and for notes contributed by his counsin, the Rev. G. H. Moule. A name for the maidenhair tree used by authors in the early Middle Ages is duck's foot: in the twelfth century, a Chinese poet spoke of "the gold of the duck's foot leaves," referring to the autumn color of the foliage. The Japanese believed that *Ginkgo* served as a protection against fire by exuding water when scorched: the Rev. G. H. Moule writes that he has seen *Ginkgo* trees blackened by flames and scarcely hurt while other trees were destroyed. The same writer refers to the hanging roots on stems of old *Ginkgo* trees in Japan which are said to symbolize women's breasts: he speaks of a tree at Sendai [2] which has been worshipped for more than a thousand years by women suffering from lack of milk and any sickness of the breasts.]

THE PAST HISTORY OF *GINKGO*

Let us first examine the nature of the evidence which enables us partially to reconstruct the past history of *Ginkgo* and other members of the Ginkgoalean group. Incomplete and fragmentary as it is, there is material enough to provide the outline of a fascinating story. It is fortunate that the leaves of *Ginkgo* can as a rule be recognized in a fossil state without much difficulty or danger of confusion with the foliage of other plants. Leaves are the chief source of our knowledge: seeds and other remains are rare and supply little more than confirmatory evidence. Form and venation and, whenever possible, the minute structure of the surface layers of leaves furnish the necessary data. A fossil leaf may agree very closely in shape and venation with leaves of the living plant;

[2] For a photograph of the Sendai tree, see A. C. Seward, Plant life through the ages, p. 521, fig. 135

but that in itself is not proof of specific identity. Fortunately, many fossils are not mere impressions on shale and sandstone—ghosts without substance; they are often covered with a black or brown film which is all that remains of the tissues. This film represents the altered or carbonized remains of the leaf substance: its surface is the resistant cuticular skin which covered the epidermal layer of the living leaf. The film can often be detached from the rock, or it may peel off naturally. By treatment with appropriate reagents it is rendered less opaque and becomes amenable to microscopical examination, revealing the cell-pattern of the epidermal layer, including the minute and vitally important stomata. The stomatal apparatus, which regulates gaseous exchange between the plant and the atmosphere, serving also as an exit for water vapor, has a characteristic structure of great value in distinguishing one genus or family from another. Focusing below the surface of the film one can sometimes see the remains of underlying tissue, crushed and contracted, and readily detect the presence of secretory cells still containing dark patches of the original products of secretion. Thus valuable evidence is obtained enabling us to compare in detail the surface layer and some of the deeper tissues with the corresponding structures in fresh leaves. By the use of modern methods of technique it has been possible to correct conclusions based solely on external form. Botanists concerned only with living plants naturally and very properly attach the greatest importance to reproductive organs as criteria of relationship. The paleobotanist is in a much less favorable position; he hardly ever finds fossil leaves and flowers preserved together, and indeed flowers are seldom available; he has, therefore, been compelled to make the best use he can of leaves, and has studied them intensively. In rare instances it is possible to examine not only the surface layer of fossil leaves but the structure of all the tissues: leaves and other parts of plants occasionally occur as petrifactions, preserved in amazing perfection. Petrified leaves are abundant in the calcareous nodules of coal seams (Carboniferous period), but in rocks belonging to periods in which the *Ginkgo* family flourished they are exceedingly rare. One of the few examples of Ginkgoalean foliage preserved in this way is mentioned on a later page.

Nearly 30 years ago the writer suggested the employment of the generic name *Ginkgoites* in place of *Ginkgo* for fossil leaves which through lack of evidence cannot be regarded as generically identical with *Ginkgo biloba*. Fossil leaves closely resembling the foliage of the maidenhair tree may have belonged to a tree having male and female flowers which differed in some important respects from those of the surviving species. Paleobotany is not an exact science: the documents which the student endeavors to decipher provide only

scraps of information, and it is desirable that this lack of precision and paucity of evidence should be implied by the terminology which a paleobotanist employs. If he has sufficient evidence to justify him in assigning fossil leaves to the genus which includes *Ginkgo biloba*, well and good; if he has no such evidence, then he admits the lack of certainty by adopting the name *Ginkgoites*. It is, however, impossible in some instances to make a satisfactory choice between the alternative generic names. For present purposes it is not worth while to discuss tiresome though unavoidable questions of nomenclature: for the sake of simplicity, rather than in accordance with strictly scientific considerations, the generic designation *Ginkgo* is adopted in the following account of fossil leaves believed to belong to trees which, if now living, would either be referred to *Ginkgo* or to a separate and very closely related genus of the same family.

FOSSIL LEAVES

The periods of geological history with which we are concerned are arranged as follows:

- Recent.
- Quaternary.
- Tertiary
  - Pliocene stage.
  - Miocene stage.
  - Oligocene stage.
  - Eocene stage.
- Cretaceous.
- Jurassic.
- Rhetic.
- Triassic.
- Permian.
- Carboniferous.

As already stated, it is not absolutely certain, though by no means improbable, that the maidenhair tree still exists as a wild tree: there can be no doubt of its natural occurrence in Far Eastern forests within the limits of the Recent period. Passing to the Quaternary period, to a time separated from the present by many thousand years, there is a record of the discovery of *Ginkgo* leaves by the Russian paleobotanist, Kryshtofovich, at a locality on the Bureya River in northeastern Siberia (approximately 50° N. lat.): good photographs of the fossils have not been seen. Descending the geological scale the next records are from Pliocene plant beds in France and Germany. Well-preserved leaves were found near Frankfort on the Main very similar in form and venation to the leaves of *Ginkgo biloba*, agreeing also in the structure of the epidermal layer, though not identical in certain details. Other examples from the Pliocene stage have been described from the Rhone Valley, where forests formerly fringed the

shores of a large gulf occupying the site of the southern part of the present river's course. These fossil leaves, superficially indistinguishable from the foliage of the living tree, with many others from Tertiary rocks, are usually spoken of as *Ginkgo adiantoides*. Specimens have been obtained from rocks belonging to all stages of the Tertiary era, particularly from the earlier or Eocene strata. Some of the most beautifully preserved leaves are from the Island of Mull, where they were collected many years ago from sedimentary deposits associated with the horizontal sheets of basalt which give the characteristic terraced profile to some of the Inner Hebrides. In the early days of the Tertiary period, subsequent to the upheaval of the floor of the Cretaceous sea, volcanic forces, which had long been dormant, broke out into activity on a stupendous scale: through fissures in the earth's crust and from volcanoes sheets of lava spread over an enormous area including northeast Ireland, the Inner Hebrides, the Faröes, Greenland, and other arctic regions. The columnar basalts of the Giant's Causeway in northern Ireland and Fingal's Cave in the island of Staffa belong to this Tertiary lava-field. The occasional occurrence of water-borne sedimentary material intercalated among the sheets of lava, as in the Island of Mull at Ardtun Head on the southwest coast, bears witness to periods of quiescence during which forests were able to colonize the lava-fields. *Ginkgo* was one of the forest trees. The leaves were first described by the late Mr. Starkie Gardner about 50 years ago, who spoke of them as indistinguishable from those of the living tree. Realizing that plants as old as the Eocene stage of the Tertiary period—a stage separated from the present by perhaps 80 million years—were probably not specifically identical with those of the present day, he referred the Mull fossils to the Tertiary species *Ginkgo adiantoides*. A recent examination of the epidermal cells of the Mull leaves by Dr. Florin of Stockholm revealed certain peculiarities which led him to rename the species *G. gardneri*. We do not know anything of the "flowers" of this species; but it is safe to assert that the Mull tree was very closely allied to *G. biloba*.

Since the discovery of fossil *Ginkgo* leaves in Tertiary rocks of northern Italy, nearly a hundred years ago, numerous specimens from Eocene and later rocks have been described from widely separated localities in arctic and temperate regions. The significant fact that emerges from a review of the evidence furnished by rocks of the Tertiary period is that species of *Ginkgo*, how many we do not know, had a far-flung geographical range: the genus was represented in forests from the Pacific coast of North America to Alaska and arctic Canada; in western and eastern Greenland as far north as latitude 74°, where leaves have been found in Tertiary rocks of Sabine Island. With many other trees *Ginkgo* flourished in Spitsbergen, in the forests

of Siberia and as far east as the western shores of the Pacific Ocean. Its territory was spread over wide tracts in both the Old and the New World, mainly in the Northern Hemisphere. It is, however, significant that in 1935 Prof. E. W. Berry, of Johns Hopkins University, recorded the discovery of Tertiary *Ginkgo* leaves in Patagonia. This fact affords impressive proof of the enormous distance over which *Ginkgo* trees had been dispersed. Tertiary records are not all from rocks of the same geological age; most of them are from the Lower Tertiary, the Eocene stage; some from Miocene and Oligocene rocks and a smaller number from the uppermost, or Pliocene stage, of the period. As the ages of the Tertiary period passed, the geographical range of the genus became more restricted until, so far as we know, only a single species remained when the Recent period began.

There is no clearly marked difference in the position occupied by the genus in the living garment of the Cretaceous earth; it was very abundant as far back as the older Cretaceous floras. The chief difference is that as we descend from the Tertiary to older periods we find a gradual increase in the number of other genera of the *Ginkgo* family. Confining attention for the moment to *Ginkgo*, it is interesting to find in rocks corresponding in age to the sediments deposited in the great Wealden lake of southern England, northern France, Belgium, and northern Germany leaves very similar in external characters to those of the maidenhair tree. Such have been discovered in Lower Cretaceous strata in Alaska, western Greenland, Franz Josef Land, northwest Germany, northern France, and elsewhere. Fossils gathered from the sedimentary beds of the still more ancient Jurassic period at many localities in both hemispheres demonstrate an almost world-wide distribution of *Ginkgo*. Some of the leaves from the Jurassic rocks near Scarborough bear a striking resemblance in size, shape, and venation to the modern type of foliage and differ only in comparatively minor structural characters. Without discussing precise correlation of plant-bearing beds within the long period embraced by the Jurassic system with its several subdivisions, it can be said with confidence that *Ginkgo* had by that time reached its maximum in abundance and geographical range. There were *Ginkgo* trees in Jurassic Australia, New Zealand, Afghanistan, Turkestan, Siberia, many parts of China, also in Japan and Korea. It grew in southern Russia, in Sardinia, and throughout Europe; it had wandered as far west as Oregon on the Pacific coast. A few specimens from Jurassic rocks of India have been assigned to *Ginkgo*, but these are less satisfactory as records than those from other regions. It is noteworthy that neither *Ginkgo* nor any other member of the family has been found in the rich Jurassic flora described some years ago from Grahamland, which members of the recent Grahamland expedition have proved to be a peninsula of the Antarctic continent

and not an island as previously supposed. The flora of Grahamland is exceptional among floras of the Jurassic age in the lack of any members of the *Ginkgo* group.

Many floras have been described from Greenland, southern Sweden, Germany, Poland, Indo-China, South Africa, and Australia as Rhetic in age: the rocks so called are intermediate in geological position between the Jurassic and the preceding Triassic period; some correspond more closely with rocks of the Lias stage at the base of the Jurassic; some are closer in age to the upper members of the Triassic system. One of the oldest leaves, which it is permissible to speak of as a species of *Ginkgo*, is from Rhetic rocks in southern Sweden: it agrees in the main with the modern leaves both in epidermal structure and in venation. Leaves apparently representing four species have been described from an Upper Triassic flora in South Africa; this is one of many indications of the abundance of trees having foliage constructed on the *Ginkgo* plan at a stage in the history of the earth when strange reptilian animals were the lords of creation. One of the South African species is almost identical in shape, size, and venation with leaves previously described from rocks of approximately the same age in Virginia. The leaves had a lamina partially divided into linear segments varying in size and reaching nearly 1 foot in breadth. The same species has been found in Upper Triassic rocks of Queensland. The exceptionally rich flora described in a series of remarkable papers by Professor Harris of Reading from material he collected, 1926–27, in the Scoresby Sound district (slightly north of lat. 70° N.) on the east coast of Greenland includes at least six species of *Ginkgo*. Some of the leaves bear a close resemblance to the maidenhair foliage not only in shape and venation but in the occurrence of secretory sacs. One of the species is peculiar in having leaves dissected into four lobes with toothed upper margins, a very unusual character. It is certain that trees with various forms of leaf more or less similar in plan to those of the maidenhair tree lived in the latter part of the Triassic period in South Africa, Argentina, Queensland, and the Northern Hemisphere. It is important to remember that the name *Ginkgo* has been used in the foregoing account for some leaves which should, strictly speaking, be assigned to *Ginkgoites*. This brief and incomplete review of fossil leaves of many ages and from many parts of the world is sufficient to justify the statement that the existing species is the last of a long line of predecessors reaching back to the latter part of the Triassic period, a stage in geological history at least 150 million years ago.

Having followed the story so far it is natural to ask how much farther into the past has the history of *Ginkgo* been traced? Assuming, as we do, that this generic type did not suddenly appear as

a novelty in the plant kingdom, where did it come from and of what sort were its ancestors? Such questions as these are ever present in the thoughts and speculations of the curious people who search for origins among the scanty and often illegible documents scattered through the rocks in the course of geological history. As we follow a group, a family, or a genus through the pile of sedimentary rocks we reach at length the earliest records, and though it may seem that the quest is ended, there always remains doubt and uncertainty whether the lack of still older fossils may be due to imperfection of the record. It was only in exceptional circumstances that samples from nature's garden were preserved in the herbaria of the rocks. As we pass from rocks containing the most ancient fossils that can be regarded with confidence as undoubted allies of the maidenhair tree to rocks older still, we discover fossil leaves which may or may not be the foliage of trees of the same lineage. Leaves from Permian and Carboniferous strata described under various names, *Ginkgophyllum*, *Psygmophyllum*, and others, though similar in form to those of *Ginkgo*, do not afford definite evidence of real affinity. The most promising of the Paleozoic genera is known as *Saportaea*, called after a French paleobotanist, the late Marquis of Saporta, a genus founded on leaves first discovered in Permian rocks of Virginia and more recently in central China: this genus may be allied to *Ginkgo;* but that is as far as one can go. The ancestral stock may be recognized some day in the petrified litter of the coal period forests; but as yet we can only guess whence the *Ginkgo* group came. We must for the present be content with the knowledge that trees of the *Ginkgo* type had risen to prominence before the close of the Triassic period and continued to flourish and occupy fresh territory in the course of the Jurassic period: they held their own in the Cretaceous period and in the earlier stages of the Tertiary era, but as the Quaternary age dawned comparatively few examples remained.

PART II

OTHER MEMBERS OF THE GINKGO FAMILY

Each of the families to which botanists have assigned the higher plants, both Angiosperms and Gymnosperms, usually contains several genera differing, it may be, widely in appearance and yet possessing certain features in common believed to be indicative of close relationship. It is generally agreed that such trees as larches, cedars, firs, and pines are all members of one family which in the course of time have deviated in their several ways from some ancestral prototype. These genera are believed to be closely related one to another because they possess in common certain features, especially those exhibited by the fertile shoots, which suggest descent from a

single ancestral stock. In attempting to classify fossil plants on a basis of natural affinity we have in most instances to use vegetative characters alone; and this is the method followed in the comparison of leaves of extinct plants with the foliage of recent species. There are very few families of plants represented in present-day floras to which only a single genus is allotted. *Ginkgo* is one of the few living genera which has a family and indeed a whole group to itself. It stands alone with no near relatives: if nothing were known of its past history it would no doubt be regarded as an old type because of the possession of certain primitive traits. Search among the debris of forests embedded in the rocks has demonstrated that the genus was formerly one of several distinguished by characters indicative of community of descent. In order to illustrate this aspect of the present historical enquiry it is necessary to devote a few pages to a sketch of the main results of paleobotanical research into the family history of *Ginkgo*, without going into technical detail.

The first genus to be considered is one known as *Baiera:* this name (after J. J. Baier, an early eighteenth-century German writer on fossils and minerals) was given as long ago as 1843 to leaves found near Bayreuth in Rhetic or Lower Jurassic rocks. In outline the leaves of *Baiera* are fan-shaped or triangular as in *Ginkgo*, but the lamina is more deeply divided into linear segments, few or many in number. It is not always possible to draw a satisfactory line between *Baiera* and *Ginkgo* from the form of the lamina alone. The leaves of *Ginkgo biloba* and those of extinct species have a fairly long and well-defined stalk: in those assigned to *Baiera* the leaf-blade is attached directly to the branch by a narrow, tapered base and lacks a leaf-stalk. In a typical *Baiera* leaf the blade is cut by deep V-shaped sinuses into narrow, linear lobes or segments, each of which is supplied with a few parallel and occasionally forked veins. Some species bore the leaves in tufts on very short shoots; in others the leaves were attached singly as in the long shoots of *Ginkgo*. It may be that some Baieras had both long and short shoots. In the structure of its epidermal cells, including the stomatal apparatus, *Baiera* is near enough to *Ginkgo* to be included in the same family. No undoubted example of *Baiera* has been found either in Tertiary rocks or in those belonging to the later stages of the Cretaceous period. A few species are recorded from the earlier Cretaceous beds, but some at least of these might more appropriately be assigned to *Ginkgo*. The genus was abundantly represented in both Jurassic and Rhetic floras and in many parts of the world, reaching as far north as lat. 70° N. in East Greenland. Some unusually large leaves have been described from Upper Triassic beds in North America, South Africa, and Australia. The oldest leaves believed to be examples of the genus are from Permian rocks. There is no doubt

that *Baiera* was a companion of *Ginkgo* in Jurassic and Triassic forests and had a wide geographical range. Its reproductive organs, so far as we know, conformed in essentials to the *Ginkgo* plan.

Another genus is *Ginkgodium*, characterized by leaves similar in venation to those of *Ginkgo* but narrower and rather different in shape: leaves of this generic type are comparatively rare; they were first described from Jurassic rocks in Japan nearly 50 years ago, and, later, recorded from Jurassic rocks in southern Russia. Nothing is known of the structure of *Ginkgodium*, and for that reason the genus is of secondary importance. In 1913 Dr. Hamshaw Thomas discovered a new type of fossil in a Jurassic plant bed in western Yorkshire, to which he gave the generic name *Eretmophyllum*. The leaves, 4 or 5 inches in length, are in shape like a rather narrow-bladed paddle, hence the name, from the Greek word *eretmon*=oar or paddle. The lamina has several parallel veins and resin sacs; the structure of the superficial layer is consistent with close affinity to *Ginkgo*. Other examples of the genus are recorded from Jurassic rocks in southern Russia, Afghanistan, and Sardinia. Despite the lack of reproductive organs it is generally believed that the leaves known as *Ginkgodium* and *Eretmophyllum* may be safely included in the *Ginkgo* group.

We now come to some genera which differ more widely in form from those of the living maidenhair tree but are confidently accepted as allies that have long been extinct. The name *Phoenicopsis* (from the Greek *Phoinikeios*=of the date or palm tree) is applied to leaves comparable in shape to pieces of ribbon a few inches long and varying from half an inch to rather more or less in breadth; the veins are approximately parallel and occasionally forked. A characteristic feature of this and certain other genera is the occurrence of leaves in a crowded bunch on a very short shoot which is clasped and hidden by tiny overlapping scales: the scales protected the shoot when it was a bud and as the bud expanded they persisted at the base of the leaf cluster. *Phoenicopsis* leaves have been described under several specific names and from many parts of the world: Siberia, Afghanistan, Turkestan, China, Japan, Spitsbergen, southern Sweden, Greenland, numerous European localities, including Great Britain, and elsewhere. The genus was very widely spread in Jurassic floras and it was also a member of Rhetic and early Cretaceous floras; it probably existed as far back in the geological time scale as the Permian period. It has been possible to investigate the epidermal structure of several species of *Phoenicopsis* and the facts thus obtained confirm the opinion of Oswald Heer, who in 1876 was the first paleobotanist to describe this old type of Ginkgoalean foliage. The very short branches, each bearing a tuft of six or more grasslike leaves, may be compared on a

small scale with the short shoots of the maidenhair tree on which a cluster of stalked leaves is borne at the apex. There is, however, this difference: in *Ginkgo* the short branch persists from year to year and bears fresh leaves each season: in *Phoenicopsis* the dwarf foliage-shoot was probably shed every autumn or after a year or two; at all events, it bore only one set of leaves. Comparison may also be made with the dwarf shoots of pines with two, three, or five needles; the chief difference is that the leaves of *Phoenicopsis* are broader and flat, and the structure of the epidermal layer is of another type. It has been customary to assign to this genus fossil leaves having a certain form and venation and borne in clusters, even though the material does not furnish any information on microscopical characters. Dr. Florin, of Stockholm, has recently described a number of leaves from Lower Cretaceous rocks associated with the basaltic lavas of the now treeless Franz Josef Land (lat. 80° N.) which, owing to their exceptional preservation, it was possible to examine in detail and elucidate their anatomical structure. He found that some leaves, though externally agreeing with *Phoenicopsis*, were sufficiently distinct in structure to be recognized as different genera.[3] One of the new genera is *Stephenophyllum*, named after Cape Stephen on the south coast of Franz Josef Land, where the specimens were discovered. Seven narrow, straplike leaves are borne on a diminutive axis surrounded at the base of the dwarf shoot by persistent bud-scales. In appearance the foliage-shoot closely resembles a *Phoenicopsis*, but distinctive anatomical features are believed to justify the institution of a new generic name. Another genus, *Windwardia*, named after the ship *Windward*, chartered by the Jackson-Harmsworth Expedition of 1896, whose members collected the material, bore dwarf, deciduous shoots, each with five or seven linear leaves about 5 inches long, distinguished from those of other Ginkgoalean trees by the absence of secretory ducts and by a few other anatomical peculiarities. A third genus instituted by Florin is *Culgoweria*, a Scottish type, so called after Culgower in Sutherland, a locality from which a collection of Upper Jurassic plants, made by the late Dr. Marcus Gunn, was described by myself in 1911. Leaves that were originally assigned to *Phoenicopsis* on the ground of external resemblance have now been examined microscopically and found to differ in certain structural features from other members of the family.

Dr. Florin's intensive study of the Franz Josef Land material led to the discovery of two more genera in this arctic flora, *Sphenobaiera* and *Arctobaiera*, both of which, as the names imply, are similar in the external characters of the foliage to *Baiera*. *Arctobaiera* is characterized by deeply divided tongue-shaped leaves borne in a

[3] A short account of Dr. Florin's admirable contribution was published in Nature, May 1, 1937.

tuft and not singly: *Sphenobaiera*, a genus founded on a piece of leaf, is distinguished by a greater degree of lobing: both show distinctive anatomical characters. Whether or not the Franz Josef Land leaves are all worthy of generic rather than specific status, it is clear from Dr. Florin's careful and illuminating researches that they furnish convincing evidence of a greater range in structural details within the *Ginkgo* alliance than was previously suspected. The main point is that there were several trees in the Jurassic and early Cretaceous forests with foliage-shoots superficially very much alike, but differing one from another in certain external and internal features; all agree more closely with *Ginkgo* than with any other living plant. It is noteworthy that Florin's genus *Sphenobaiera* has been recognized by Professor Harris as one of several members of the Ginkgoalean group in the Lower Jurassic-Rhetic flora of East Greenland.

Reference has already been made to the amazingly rich flora first discovered by Dr. Hartz, of Copenhagen, in Rhetic strata at Scoresby Sound in East Greenland and more recently investigated with great thoroughness by Professor Harris, who collected a large amount of new material. The flora included many representatives of the *Ginkgo* family, new species of genera previously recorded from other regions and, in addition, a new type to which the name *Hartzia* has been given. This genus, like many of the others, bore its long and relatively narrow leaves in groups on dwarf shoots, but the lamina of each leaf had a forked tip. The stomata differ in arrangement and structure from those of *Phoenicopsis*.

Torellia.—This generic name, after Professor Torell, a geologist, was given nearly 60 years ago to leaves discovered by Captain Feilden, a member of the *Alert* and *Discovery* arctic expedition (1875–76) in early Tertiary rocks in Grinnell Land (81° 46′) and subsequently recorded from Spitsbergen. The leaves of *Torellia* may be compared with broad and stiff blades of grass 2 or 3 inches long, furnished with several parallel veins, tapering to a narrow base and rounded at the tip. In some forms the blade is sickle-shaped. *Torellia* has since been found in Cretaceous rocks of Ussuriland in eastern Siberia. The genus was in existence as long ago as the Rhetic period in the forests of East Greenland. It is noteworthy that Dr. Florin, after examining the structure of *Torellia* leaves from Spitsbergen, decided to remove them to a new genus, *Pseudotorellia*, because of certain distinctive characters.

Czekanowskia.—In 1876, Professor Heer of Zürich described some very narrow, almost hairlike leaves from Jurassic rocks in Siberia, which he named *Czekanowskia*, after the geologist Czekanowski, and referred to the *Ginkgo* family. Data subsequently obtained confirm Heer's estimate of affinity. The leaves were attached to a

very short, scale-covered axis and borne in a cluster, resembling the bunch of leaves of a five-needled pine: each leaf has two or more veins forked once or more. Several species of *Czekanowskia* are known from Jurassic rocks in arctic regions, Europe, and Asia. In epidermal characters the leaves conform more closely to the *Ginkgo* pattern than to that of any other surviving Gymnosperm.

Nothing has been written in this article on seeds or other reproductive organs associated with Ginkgoalean leaves in widely scattered parts of the world and in rocks of many ages: this is not because they are unimportant; they are of the greatest value to the paleobotanist. The reason is that it is seldom possible to connect together leaves and reproductive organs, owing to the fact that they are preserved in the sediments of estuaries and lakes as separate scraps which fell from the parent trees and were carried by rivers to their resting-place. It is, however, important to note that the remains of such reproductive organs as it has been possible to examine with any degree of thoroughness, furnish valuable data supplementary to evidence of affinity obtained from foliage-shoots.

THE WORLD-WIDE WANDERING OF GINKGO AND ITS ALLIES

A survey of the voluminous publications in which are recorded discoveries of fossil plants referred on good evidence to the *Ginkgo* alliance demonstrates the extraordinary vitality and resiliency of the genera and their success as travelers over wide spaces. It would extend this sketch far beyond reasonable limits were reference made to all the species and the places where they have been found. It is also impossible in a general summary to make comparison of the distributional areas of the several genera. The black dots on the map (fig. 1) indicate localities where members of the family have been found in rocks ranging from Triassic to the end of the Tertiary period. Though by no means a complete record, the map serves to illustrate the light thrown by paleobotanical data on the wandering of these Ginkgoalean trees never seen in life by man and known only as fragments preserved in the rocks. The tenacity with which a single member of this once vigorous group held on to life through the ages has enabled us to read the story of its ancestry.

CONCLUSION

In the foregoing pages my purpose has been to present the more important results of research into the history of the *Ginkgo* family. *Ginkgo biloba*, the maidenhair tree, is worthy of special regard as one of the most impressive examples in the plant kingdom of a link with remote ages and as the sole representative in the modern world of a family, which millions of years ago occupied as prominent a place in

the vegetation of the world as that now held by the oaks and other familiar forest trees included in the oak family. Omitting any further reference to the Paleozoic fossils, mentioned on a previous page as possible though doubtful members of the Ginkgoalean stock, the main historical conclusions may be summarized as follows (see fig. 2).

As the Triassic period drew to its close more than 150 million years ago, the surface of the earth bore little or no resemblance to that with which we are familiar. At that stage in geological history and during many million years that followed, the distribution of land and water, mountains, valleys, and plains, animal and plant communities, and climatic conditions reflected in their gradual transformation the cycles of physical and organic evolution. Even in the Triassic period there were a few plants foreshadowing more or less clearly trees that are

FIGURE 1.—Map of the distribution of *Ginkgo* and allied genera in former periods of geological history. The area within which *Ginkgo* may still exist as a wild tree is shown by the circle below 30° N. lat. on the eastern edge of China. The records on which the map is based are from the Triassic to the Quaternary period.

still living. Conspicuous in this small company were representatives of the Ginkgoalean family, notably *Baiera* and *Ginkgo*. Passing upward to the Jurassic period we find other genera added to the growing family, genera which established themselves over a vast extent of territory both north and south of the Equator. It was at this stage in the history of the earth that *Ginkgo*, *Baiera*, *Phoenicopsis*, *Czekanowskia* and other genera reached their greatest development as measured by the number of species and geographical range. As the Jurassic period merged into the Cretaceous, the balance of nature was not seriously disturbed: many genera survived the change. But the Ginkgoalean race had passed its zenith. There followed a much more drastic physical revolution when the Cretaceous sea, in which the material of our chalk downs was made from the calcareous skeletons of marine creatures, flooded vast continental areas—a revolution which had a far-reaching effect upon contemporary life.

When the floor of the Cretaceous sea had been raised into land and the calcareous ooze of the ocean was converted into hills of chalk, the plant world assumed a much more modern aspect. In the Tertiary floras preserved in sedimentary deposits of post Cretaceous age *Ginkgo* was almost, though not quite, the sole survivor or the family; it was still a vigorous and widely dispersed tree in

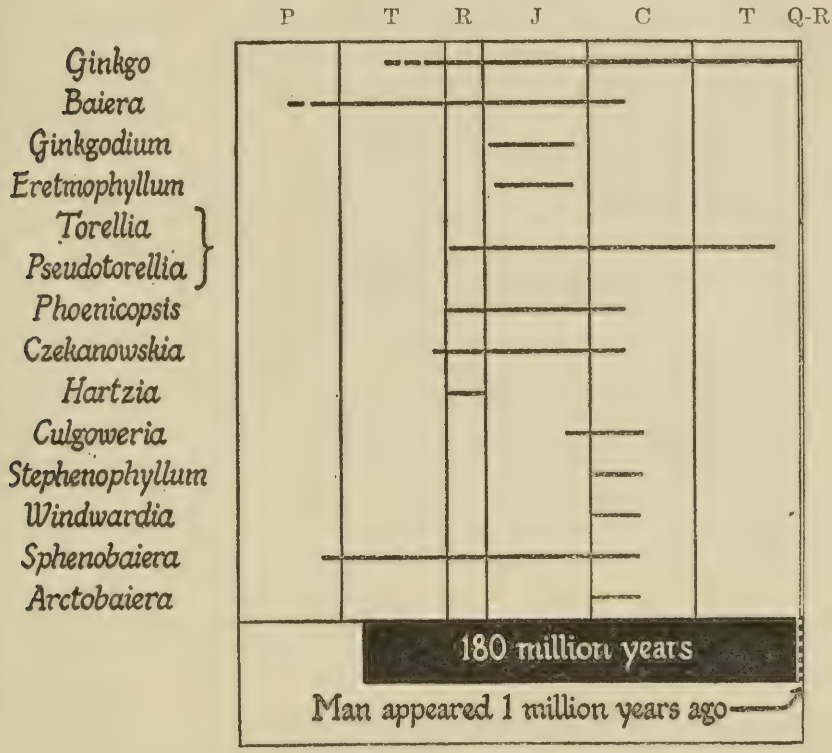


FIGURE 2.—Diagram illustrating the approximate distribution in time of genera of the Ginkgoales.

P—Q—R = Permian, Triassic, Rhetic, Jurassic, Cretaceous, Tertiary, Quaternary and Recent periods. The relative antiquity of the Ginkgoales and the human race is indicated by the black time scale. According to the late Prof. Elliot Smith (Human History) man "must have been alive during the Pliocene stage." Prof. A. Holmes (The Age of the Earth) gives the date of the Triassic period as 180 million years. The name *Ginkgo* is used in a wide sense, including some species which should be assigned to *Ginkgoites*. It is important to note that the genera *Stephenophyllum* and others shown in the Table as Lower Cretaceous were founded on exceptionally well-preserved fossils from Franz Josef Land; in all probability, were equally good material available from other places, they would be found to have had a much greater range in time and in space. The diagram is not drawn to scale except that the Rhetic period, transitional between the Triassic and Jurassic, is shown as a shorter phase of geological history.

American, Arctic, European, and Asiatic forests. Even as late as the last, or Pliocene, stage of the Tertiary period *Ginkgo* still lingered on in Europe. It is probable that the genus was unable to endure the severe arctic conditions which swept over an enormous area in the Old and the New World when the genial climate of the Tertiary age was followed by a glacial phase. *Ginkgo* lived on in the Quaternary period, the

sole relic of a race threatened with extinction. Driven hither and thither by adverse circumstances, this symbol of departed glory eventually found a refuge in the Far East. It was not until the family had been reduced to a few species and a single genus that man came into the world, and in a later stage of his development assisted nature by his care of one of her oldest treasures.

Ginkgo has for centuries appealed to the imagination of the Oriental mind: the tree with leaves like golden ducks' feet became an object of veneration; a legacy, it might be, from a golden age and as such possessing miraculous power. We, despite our more matter-of-fact western outlook, pay homage to the sacred tree of the East because its story, written in the sands of time, gives us a vision of enduring life. The maidenhair tree appeals to the historic soul: we see it as an emblem of changelessness, a heritage from worlds of an age too remote for our human intelligence to grasp, a tree which has in its keeping

> The secrets of the immeasurable past.

THE WATER-CULTURE METHOD FOR GROWING PLANTS WITHOUT SOIL[1]

By D. R. Hoagland and D. I. Arnon
California Agricultural Experiment Station

[With seven plates]

INTRODUCTION

During the past few years, the popular press has given an immense amount of publicity to the subject of commercial or amateur growing of crops in "water culture;" that is, growing plants with their roots in a solution containing the mineral nutrients essential for plant growth. The solution takes the place of soil in supplying water and mineral nutrients to the plant. This method of growing plants is also described under such names as "tray agriculture," "tank farming," and the recently coined term, "hydroponics." Often, popular accounts of recent experiments on growing plants by the water-culture method leave the reader with the impression that a new discovery has been made which bids fair to revolutionize our present methods of crop production, and indeed promises to produce in the future far-reaching social dislocations by dispensing with the soil as a medium for growing many crops.

Frequently, wholly unfounded claims have been made by promoters that a new "profession of soilless farming" has been developed which offers extraordinary opportunities for investment of time and funds. Attempts have been made to convince the public that a short course of training will give preparation for entering this new "profession." The impression has been given also that the water-culture method offers an easy means of raising food for household use.

Some of the popular articles on the water-culture method of crop production are grossly inaccurate in fact and misleading in implication. Widely circulated rumors, claims, and predictions about the water-culture production of crops often have little more to commend them than the author's unrestrained imagination. Erroneous and

[1] This article has also been published as a circular of the California Agricultural Experiment Station. It was originally prepared at the request of the director of this station for the purpose of presenting an independent appraisal of the water-culture method in the light of recent discussion. Here printed by permission of the California Agricultural Experiment Station.

even fantastic ideas have been conceived, betraying a lack of knowledge of elementary principles of plant physiology. For example, there have been statements that in the future most of the food needed by the occupants of a great apartment building may be grown on the roof, and that in large cities "skyscraper" farms may supply huge quantities of fresh fruit and vegetables. One Sunday supplement article contained an illustration showing a housewife opening a small closet off the kitchen and picking tomatoes from vines growing in water culture, with the aid of electric lights. There has even arisen a rumor that the restaurants of a large chain in New York City are growing their vegetables in basements.

Stories of this kind have gained wide currency and have captured the imagination of many persons. Many factors have doubtless contributed to arousing the surprisingly wide interest in the water-culture method of crop production. The psychological effect of current discussion of the wastage of soil erosion and soil depletion has made the public especially receptive to new ideas relating to crop production. Some people have been impressed by the assumed social and economic significance of the water-culture method. Others, moved by the common delight of mankind in growing plants, even though the garden space is reduced to a window sill, have sought directions to enable them to try a novel technique of plant culture. The consequence of the discussion of this method has been the creation of a great public demand for more specific information. Should this newly aroused interest in plant growth lead to a greater diffusion of knowledge of certain general principles of plant physiology, the publicity regarding the water-culture method of crop production might in the long run have a beneficial effect. Growing plants in water culture has been considered by some popular writers as a "marvel of science." The growth of plants is indeed marvelous, but not more so when plants are grown in water culture than when they are grown in soil.

Sometimes two entirely distinct lines of investigation at the California Agricultural Experiment Station, in which the water-culture technique is used, have been confused in popular discussions. One of these concerns methods of growing plants in water culture under natural light, the other the study of special scientific problems of plant growth in controlled chambers artificially illuminated. It is economically impossible at the present time to grow crops commercially solely under artificial illumination, even if there were any reason for doing so. At several other institutions considerable attention has been devoted to study of the effect of supplementing daylight with artificial light during some seasons of the year, to control the flowering period or to accelerate growth of certain kinds of plants (particularly floral plants) in greenhouses, but this practice has mainly been applied

so far to plants developed in soil and has no essential relation to the water-culture method of growing plants.

HISTORICAL SKETCH OF THE DEVELOPMENT OF THE WATER-CULTURE METHOD

Curiously enough, the earliest recorded experiment with water cultures was carried out in search of a spurious "principle of vegetation" in a day when the general ignorance of the principles of plant nutrition seemingly precluded the undertaking of a profitable experiment. Woodward, about 1699, grew spearmint in several kinds of water: rain, river, and conduit water to which he in one case added garden mold. He found that the greatest increase in the weight of the plant took place in the water containing the greatest admixture of soil. His conclusion was, "That earth, and not water, is the matter that constitutes vegetables."

The real development of the technique of water culture took place about three-quarters of a century ago and came as a logical result of the crystallization of the modern concepts of plant nutrition. By the middle of the nineteenth century, enough of the fundamental facts of plant physiology had been accumulated and properly evaluated to enable the botanists and chemists of that period to assign correctly to the soil the role which it plays in the nutrition of plants. They realized that plants are made of chemical elements obtained from three sources: air, water, and soil; and that the plants grow and increase in size and weight by combining these elements into various plant substances.

The major portion, usually about 90 percent, of the dry matter of most plants (water is, of course, always the main component of growing plants) is made up of three chemical elements: carbon, oxygen, and hydrogen. Carbon comes from the air, oxygen from the air and from water, and hydrogen from water. In addition to the three elements named above, plants contain other elements, such as nitrogen, phosphorus, potassium, and calcium, which they obtain from the soil. The soil, then, supplies to the plant a large number of chemical elements, but they constitute only a very small portion of the plant's composition. It was early understood, however, that various elements which occur in plants in comparatively small amounts are just as essential to their growth as those which compose the bulk of plant tissues.

The publication, in 1840, of Liebig's book, The Application of Organic Chemistry to Agriculture and Physiology[2] in which the above views were ably and effectively brought to the attention of plant physiologists and chemists of that period, served as a great stimulus for the undertaking of experimental work in plant nutrition.

---

[2] Von Liebig, Justus, Chemistry in its applications to agriculture and physiology, English trans., 401 pp. John Wiley, New York, 1861.

(Liebig, however, failed to understand the role of soil as a source of nitrogen for plants, and the fixation of atmospheric nitrogen by bacteria was not then known.)

Once it was recognized that the function of the soil in the economy of the plant is to furnish certain chemical elements, as well as water, it was but natural to attempt to supply these elements and water independently of soil. The credit for initiating exact experimentation in this field belongs to the French chemist, Jean Boussignault, who is regarded as the founder of modern methods of conducting experiments in vegetation.

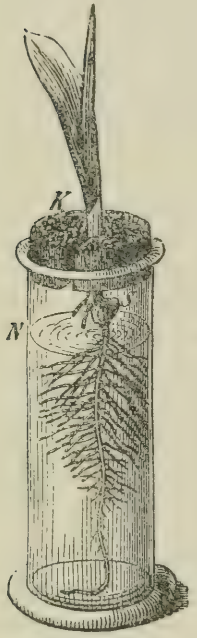


FIGURE 1.—Water-culture installation employed by the plant physiologist Sachs in the middle of the last century.
(Reproduced from Sachs, Lectures on the Physiology of Plants. Clarendon Press, 1887.)

Boussignault, who had begun his experiments on plants even before 1840, grew them in insoluble artificial soils: sand, quartz, and sugar charcoal, which he watered with solutions of known composition. His results provided experimental verification for the mineral theory of plant nutrition as put forward by Liebig, and were at once a demonstration of the feasibility of growing plants in a medium other than a "natural soil." This method of growing plants in artificial insoluble soils was later improved by Salm-Horstmar (1856–60) and has been used since, with various technical improvements, by numerous investigators throughout the world. In recent years, large-scale techniques have been devised for growing plants for experimental or commercial purposes in beds of sand or other inert solid material.

After plants were successfully grown in artificial culture media, it was but one more step to dispense with any solid medium and attempt to grow plants in water to which the chemical elements required by plants were added. This was successfully accomplished in 1860 by Sachs and about the same time by Knop. To quote Sachs directly: [3]

> In the year 1860, I published the results of experiments which demonstrated that land plants are capable of absorbing their nutritive matters out of watery solutions, without the aid of soil, and that it is possible in this way not only to maintain plants alive and growing for a long time, as had long been known, but also to bring about a vigorous increase of their organic substance, and even the production of seed capable of germination.

The original technique developed by Sachs for growing plants in nutrient solutions is still widely used, essentially unaltered. He germinated the seed in well-washed sawdust, until the plants reached a size convenient for transplanting. After carefully removing and

[3] von Sachs, Julius. Lectures on the physiology of plants, p. 283, Clarendon Press, Oxford, 1887.

washing the seedling, he fastened it into a perforated cork, with the roots dipping into the solution. The complete assembly is shown in figure 1, which is a reproduction of Sachs' illustration.

Since the publication of Sachs' standard solution formula (table 1) for growing plants in water culture, many other formulas have been suggested and widely used with success by many investigators in different countries. Knop, who undertook water-culture experiments at the same time as Sachs, proposed in 1865 a nutrient solution, which became one of the most widely employed in studies of plant nutrition. Other formulas for nutrient solutions have been proposed by Tollens in 1882, by Schimper in 1890, by Pfeffer in 1900, by Crone in 1902, by Tottingham in 1914, by Shive in 1915, by Hoagland in 1920, and many others.

TABLE 1.—*Composition of nutrient solutions employed by early investigators* [1]

Sachs' solution (1860)		Knop's solution (1865)		Pfeffer's solution (1900)		Crone's solution (1902)	
Ingredient	Grams per 1,000 cc H_2O	Ingredient	Grams per 1,000 cc H_2O	Ingredient	Grams per 1,000 cc H_2O	Ingredient	Grams per 1,000 cc H_2O
KNO_3	1.00	$Ca(NO_3)_2$	0.8	$Ca(NO_3)_2$	0.8	KNO_3	1.00
$Ca_3(PO_4)_2$	.50	KNO_3	.2	KNO_3	.2	$Ca_3(PO_4)_2$	.25
				$MgSO_4$	.2	$MgSO_4$	.25
$MgSO_4$	.50	KH_2PO_4	.2	KH_2PO_4	.2	$CaSO_4$	.25
$CaSO_4$	.50	$MgSO_4$	.2	KCl	.2	$FePO_4$	.25
$NaCl$	.25	$FePO_4$	Trace	$FeCl_3$	Small amount		
$FeSO_4$	Trace						

[1] These and other formulas are given in: Miller, E. C., Plant physiology, pp. 195–197, McGraw-Hill Book Co., New York, N. Y., 1931. For best results, these solutions should be supplemented with boron, manganese, zinc, copper, and molybdenum, as described in the text, p. 487, if distilled water is used in the preparation of the nutrient solution.

At the very inception of the water-culture work, investigators clearly recognized that there can be no one composition of a nutrient solution which is always superior to every other composition, but that within certain ranges of composition and total concentration, fairly wide latitude exists in the nutrient solutions suitable for plant growth. Thus Sachs wrote:

> I mention the quantities (of chemicals) I am accustomed to use generally in water cultures, with the remark, however, that a somewhat wide margin may be permitted with respect to the quantities of the individual salts and the concentration of the whole solution—it does not matter if a little more or less of the one or the other salt is taken—if only the nutritive mixture is kept within certain limits as to quality and quantity, which are established by experience.

Until recently, the water-culture technique was employed exclusively in small-scale, controlled laboratory experiments intended to elucidate fundamental problems of plant nutrition and general physiology. These experiments have led to the determination of the list of chemical elements essential for plant life and have thus profoundly influenced the practice of soil management and fertilization for purposes of crop

production.[4] In recent years, great refinements in water-culture technique have made possible the discovery of several new essential elements, which, although required by plants in exceedingly small amounts, often are of definite practical importance in agricultural practice. The elements derived from the nutrient medium that are now considered to be indispensable for the growth of higher green plants are nitrogen, phosphorus, potassium, sulphur, calcium, magnesium, iron, boron, manganese, copper, and zinc. New evidence suggests that molybdenum may have to be added to the list.[5] Present indications are that further refinements of technique may lead to the discovery of still other elements, essential in minute quantity for growth.

In addition to the list of essential elements, which is obviously of first importance in making artificial culture media for growing plants, a large amount of information has been amassed on the desirable proportions and concentrations of the essential elements, and on such physical and chemical properties of various culture solutions as acidity, alkalinity, and osmotic characteristics. A most important recent development in water-culture technique has been the recognition of the importance for many plants of special aeration of the nutrient solution, to supplement the oxygen supply normally gaining access to the solution when it is in free contact with the surrounding atmosphere.

The recently publicized use of the water-culture technique for commercial crop production does not rest on any newly discovered principles of plant nutrition other than those discussed above. It involves, rather, the application of a large-scale technique, developed on the basis of an understanding of plant nutrition gained in previous investigations conducted on a laboratory scale. The latter have provided an understanding of the composition of suitable culture solutions. Furthermore, methods of controlling the concentration of nutrients and the degree of acidity are, except for modifications imposed by the large scale of operations, similar to those employed in small scale laboratory experiments.

The selection of a particular type of covering for the tanks adapted to large-scale water-culture operations and of methods for supporting the plants depends on the kind of plant. For example, in growing potatoes by the water-culture method, provision must be made for a suitable bed above the level of the solution, in which tubers can develop. On the other hand, in growing tomatoes it is only necessary to provide adequate support for the aerial portion of the stem, assuming that the roots are in a favorable culture-solution medium, ade-

[4] However, nutrient solutions such as are employed in water-culture experiments are not applied directly to soils. For discussion of fertilizer problems consult: Hoagland, D. R., Fertilizer problems and analysis of soils in California, Calif. Agr. Exp. Stat. Circ. 317, pp. 1–15, revised 1938.

[5] Unpublished data of D. I. Arnon and P. R. Stout.

quately aerated, and with light excluded; a porous bed may be convenient as a means of facilitating aeration of the solution, as a heat insulator, or as a support for the plant, but plays no indispensable role. Aside from such considerations, the choice of a covering is determined largely by expense and convenience, provided the materials used are not toxic to plants.

With any kind of covering for the tanks, an adequate supply of air to the roots must be provided. While the use of a porous bed instead of a perforated cover facilitates aeration of roots, the bed can be dispensed with if provision is made to bubble air through the nutrient solutions (pl. 1). Recent experiments have shown that even with the use of a porous bed, bubbling air through the solution may be advantageous or, under some conditions, indispensable.

For approximately a quarter of a century investigations have been conducted at the University of California on problems of plant nutrition with the use of the water-culture technique, as one important method of experimentation. The objective has been to gain a better understanding of fundamental factors which govern plant growth, in order to deal more effectively with the many complex problems of soil and plant interrelations in the field. As illustrations of some scientific problems of plant nutrition which have been elucidated by the aid of the water-culture method of experimentation, the effects of aeration of the roots on plant growth are shown in plate 2, figure 1, and the effects of deficiencies of mineral elements required in minute quantity in plate 2, figure 2.

Many workers have participated in these investigations. One of them, W. F. Gericke, conceived some time ago that the water-culture method, hitherto employed only for scientific studies, might be adapted to commercial use. In experiments carried on in the greenhouses and experimental gardens of the university, he grew plants in water culture on a scale larger than that used in earlier investigations and devised a method of superimposing a porous bed over the nutrient solution. This development was soon given widespread publicity in newspapers and popular journals. The public became fascinated with the idea of growing plants in a medium other than soil. Many thousands of inquiries have come to the University of California requesting detailed information which would make possible the general application of the water-culture method by commercial concerns or by amateur gardeners.

This article, based largely on experience of its authors,[6] was prepared to make available information for which a great public demand had arisen. Although in view of the complexity of the problem the

[6] The authors, however, disclaim any credit for suggesting the use of the water-culture method for commercial purposes.

114728—39——31

California Agricultural Experiment Station has no recommendations to offer at this time for the general use of the water-culture method, it seems proper and necessary that those who wish to experiment with this method on their own responsibility should have accessible a popular account of the information now available from the researches of the Agricultural Experiment Station.

The method of water culture is, as previously indicated, not the only one for growing plants without soil. Several other experiment stations have developed large-scale techniques of sand or gravel culture. These involve the periodic flooding, or subirrigation, of a solid medium with nutrient solutions similar to those employed in the water-culture method. Some investigators hold the opinion that the sand- or gravel-culture methods have certain advantages in practical use over the water-culture method, particularly in respect to conditions of aeration of the root system.[7]

PRINCIPLES AND APPLICATION OF THE WATER-CULTURE METHOD

The purpose of this circular is to give an account of the water-culture method as a means of supplying mineral nutrients and water to plants. The absorption of nutrient salts and water are only two of the physiological processes of the plant. In order to evaluate the possibilities and limitations of any special technique for growing plants, one has to understand the significance of other interrelated processes, especially photosynthesis, respiration, transpiration, and reproduction.

IMPORTANCE OF CLIMATIC REQUIREMENTS

Many inquiries have been received on the possibility of growing plants in water culture in dimly lighted places, or at low temperatures, under conditions which would prevent growth of plants in soil. Obviously, no nutrient solution can act as a substitute for light and suitable temperature. If doubt is entertained of the suitability of a particular location or season for the growth of any kind of plant, a preliminary experiment should be made by growing the plant in good garden soil. If the plant fails to make satisfactory development in the soil medium

[7] Further information on the sand- and gravel-culture methods may be obtained from the following publications:

Withrow, R. B., and Biebel, J. P., Nutrient solution methods of greenhouse crop production. Indiana (Purdue Univ.) Agr. Exp. Stat. Circ. 232, pp. 1–16, 1937.

Biekart, H. M., and Connors, C. H., The greenhouse culture of carnations in sand, New Jersey Agr. Exp. Stat. Bull. 588, pp. 1-24, 1935.

Shive, J. W., and Robbins, W. R., Methods of growing plants in solution and sand cultures, New Jersey Agr. Exp. Stat. Bull. 636, pp. 1–24, 1938.

Eaton, Frank M., Automatically operated sand-culture equipment, Journ. Agr. Res., vol. 53, pp. 433–44, 1936.

Chapman, H. D., and Liebig, George F., Jr., Adaptation and use of automatically operated sand-culture equipment, Journ. Agr. Res., vol. 56, pp. 73–80, 1938.

because of unfavorable light or temperature, failure may also be expected under water-culture conditions. Sunlight and suitable temperatures are essential for green plants, in order that they may carry on one of the fundamental processes of plant growth, known as photosynthesis. In this process, the element carbon, which forms so large a part of all organic matter, is fixed by plants from the carbon dioxide of the atmosphere. This reaction requires a large amount of energy, which is obtained from sunlight.

Plants depend on photosynthesis for their food, that is, organic substances, such as carbohydrates, fats, and proteins, which provide them with energy and enter into the composition of plant substance. The mineral nutrients absorbed by roots are indispensable for plant growth, but they do not supply energy, and in that sense, cannot be regarded as "plant food." Animal life is also absolutely dependent on the ability of the green plant to fix the energy of sunlight.

TEMPERATURE RELATIONS

An earlier report of a preliminary experiment by other investigators suggested that under greenhouse conditions heating the nutrient solution would produce large increases in the yield of tomatoes.[8] Experiments that we have carried on with tomatoes in a Berkeley greenhouse (unheated except on a few occasions to prevent temperatures from falling below 50°–55° F.) have now given evidence that under the climatic conditions studied, the beneficial effects of heating the nutrient solution (to 70°–75° F.) are not of significance. If favorable air temperatures are maintained, there seems to be no need to heat the solution. Attempts should not be made to guard against frost injury or unfavorable low air temperatures merely by heating the nutrient solution. Proper provision should be made for direct heating of the greenhouse. This may be found desirable even when danger from low temperatures is absent, in order to control humidity and certain plant diseases.

These experiments on tomatoes suggest that if greenhouse temperatures are properly controlled, the solution temperature will take care of itself. Certainly no expense, either in a greenhouse or outdoors, should be incurred for equipment for heating solutions until experimentation has shown that such heating is profitable. There is no one best solution temperature. The physiological effects of the temperature of the solution are interrelated with those of air temperature and of light conditions.

Most amateurs who try the water-culture method will grow plants in warm seasons and probably will not wish to complicate their

[8] Gericke, W. F., and Tavernetti, J. R., Heating of liquid culture media for tomato production, Agr. Eng., vol. 17, pp. 141–142, 184, 1936.

installation by the addition of heating devices. Anyone who desires to test the influence of heating the culture solution should make comparisons of plants grown under exactly similar conditions, except for the difference of temperature in the solutions.

COMPARISONS OF YIELDS BY SOIL AND WATER CULTURE

The impression conveyed by most of the popular discussions of the water-culture method is that the inherent productive capacity of a given surface of nutrient solution far surpasses that of an equivalent surface of soil, even under the best soil conditions feasible to maintain. Often quoted is the yield of tomato plants grown for a 12 months' period in a greenhouse water-culture experiment in Berkeley.[9] This yield is compared with average yields of tomatoes under ordinary field conditions, and the yield from the water-culture plants is computed to be many times greater. But closer analysis shows that erroneous inferences may be drawn from this comparison. Predictions concerning yields in large-scale production are of doubtful validity when based on yields obtained in small-scale experiments under laboratory control. In any event, there is little profit in comparing an average yield from unstaked tomato plants grown during a limited season under all types of soil and climatic conditions in the field, with yields from staked plants grown in the protection of a greenhouse for a full year. Evidence has long been available that yields of tomatoes grown in a greenhouse, in soil, can far exceed yields obtained in the field. It is true that in one series of outdoor experiments, the yields of tomatoes under water-culture conditions were reported to be much higher than under ordinary field conditions, on a unit-surface basis; but again, the general cultural treatment of the plants (especially with regard to spacing and staking) was so different that comparisons of yield are of very limited value. Furthermore, the equipment for an acre of water-culture plants would be very costly, and technical supervision of the cultures and the labor of staking vines would necessitate large and as yet unpredictable expenditures.

A real test of the relative capacities of soil and water-culture media for crop production requires that the two types of culture be carried on side by side, with similar spacing of plants and with the same cultural treatment for plants grown in soil and water culture. The soil should be of suitable depth and have its nutrient supplying power and physical condition as favorable for plant growth as possible. We initiated an experiment of this kind in Berkeley late last summer, with the tomato as the test plant. The experiment has now been carried on over a full year, and several of the conclusions derived from it warrant emphasis. The yield of tomatoes grown by the usual

[9] Gericke, W. F., Crop production without soil. Nature, vol. 141, pp. 536–540, 1938. See also the article cited in footnote 8, p. 469.

tank-culture technique was larger than any heretofore reported as obtained by this method. The yield from the soil-grown plants, however, was not significantly different from that of the plants grown by the tank method (pl. 3). When the greenhouse yields of tomatoes from either soil or solution-grown plants were computed on an acre basis and compared with average yields of field-grown tomatoes, the greenhouse plants gave far greater yields. But as already suggested, such comparisons have no direct practical significance because of the differences of climatic factors, cultural practice, and length of season in the greenhouse and in the open field.

In one California commercial greenhouse, the yields of tomatoes grown in soil were of the same magnitude as those obtained in a successful commercial greenhouse employing the water-culture procedure, and in another greenhouse using soil the yields were larger.

Recently, data have become available on yield of potatoes grown in a bed of peat soil in Berkeley. This yield was as large as any heretofore reported as produced by the water-culture method.

The suggestion has sometimes been advanced that plants can be grown more closely spaced in nutrient solutions than in soil, but no convincing evidence of this has been given. In our experiments, we were able to grow tomato plants as close together in the soil as in the solution (pl. 3). The density of stand giving the highest yields would be determined by the adequacy of the light received by the plants when growth is not limited by the supply of nutrients or water derived from either soil or nutrient solution. Closeness of spacing under field conditions is, of course, limited by practical considerations involving cost of crop production. This consideration of economic factors and of the adequacy of light for plant growth does not justify the view that the water-culture medium is better adapted than soil to growing several different crops simultaneously in the same bed.

Published pictures of tomato plants grown in water culture show impressive height, and this growth in length of vines is frequently the subject of popular comment. As a matter of fact, the ability of tomato vines to extend is characteristic of the plant and not peculiar to the water-culture method. Staked plants grown for a sufficiently long period in a fertile soil, under favorable light and temperature conditions, can also reach a great height and bear fruit at the upper levels (pl. 4). In commercial greenhouse practice, growers usually "top" the vines. Fruit developed at higher levels is likely to be of inferior quality, and relatively expensive to produce because of labor required to attach supports to the vines, and the inconvenience of harvesting. Furthermore, it may become profitable to discontinue the tomato harvest when prices become low in the summer and use the greenhouse space to plant another crop for the winter harvest.

There is no magic in the growth of plants in water culture. This is only another way of supplying water and essential mineral elements to the plant. Land plants have become adapted to growing in soils during their evolutionary history, and it is not reasonable to expect some extraordinary increase in their potentialities for growth as a result of the substitution of an artificial medium for a soil. If no toxic conditions are present and a fully adequate supply of water, mineral salts, and oxygen is provided to the root system, either through an artificial nutrient solution or a soil, then in the absence of plant diseases and pests, the growth of a plant is limited by its genetic constitution and by climatic conditions.

NUTRITIONAL QUALITY OF PLANT PRODUCT

Modern research on vitamins and on the role in animal nutrition of mineral elements has justly aroused great public interest, but unfortunately one of the results is much popular discussion of diets and their influence on health which is without scientific basis. It is, therefore, not unexpected that claims have been advanced that food produced by the water-culture method is superior to that produced by soil.

As part of our investigation, careful studies of chemical composition and general quality have been made on tomatoes of several varieties grown in fertile soil and in water-culture media, side by side in the same greenhouse, and with the same general cultural treatment. No significant difference has been discovered in the mineral content of the fruit developed on plants grown in the two media. (There is no scientific basis for referring to tomatoes grown in water culture as "mineralized.")

Neither could any significant difference be found in content of vitamins (carotene, or provitamin A, and vitamin C). Tomatoes harvested from the soil and water cultures could not be consistently distinguished in a test of flavor and general quality.[10]

Concerning the mineral content of tomatoes, it may further be added, as a point of general interest, that all tomatoes contain but very small amounts of calcium and are not an important source of this mineral element in the diet.

The similarity in composition and general quality of the tomatoes grown in soil and water culture in the present experiments, is explained by the fact that the climate and time of harvest were comparable and the supply of mineral nutrients adequate in both cases. Whether plants are grown in soil or water culture, climate and time of harvest are, of course, of greatest importance in influencing quality and composition of plant product.

---

[10] The quality tests were conducted by Dr. Margaret Lee Maxwell, of the Division of Home Economics, and the carotene determinations were made by Dr. Gordon Mackinney, of the Division of Fruit Products, College of Agriculture.

Claims of unusual nutritional value for food products from certain sources should not be accepted unless supported by results obtained in research institutes of high standing.

PRESENT STATUS OF THE COMMERCIAL WATER-CULTURE METHOD

What is the justification for considering the water-culture method as a means of commercial crop production? The answer to this question is that the method has certain possibilities in the growing of special high-priced crops, particularly out of season in greenhouses, in localities where good soil is not available, or when maintenance of highly favorable soil conditions is found too expensive. Soil beds in greenhouses often become infected with disease-producing organisms, or toxic substances may accumulate. Installation of adequate equipment for sterilizing soils and operation of the equipment may require considerable expense. Also, in theory at least, a water-culture medium, when expertly supervised, should be subject to more exact control than a soil medium.

Present information does not warrant a prediction as to how widely the water-culture method will find practical application in greenhouses. One firm in California has reported success with this method in the production of tomatoes; another California firm which invested a large sum in equipment, met such serious difficulties that the equipment was not being utilized at last report. We suggest that those who contemplate installation of the water-culture method for commercial purposes, make a preliminary test with a few tanks of solution to compare the yields from soil and water-culture media, and to learn some of the requirements for control of the process. However, without some expert supervision, commercial success is unlikely.

Indispensable to profitable crop production by the water-culture method is a general knowledge of plant varieties, habits of growth, and climatic adaptations of the plant to be produced, pollination, and control of disease and insects; in other words, the same experience now needed for successful crop production in soils.

The above discussion is primarily based on experiments with greenhouse crops. Conceivably in regions highly favored climatically, and with a good water supply available, but where soil conditions are adverse, some interest may arise in the possibilities of growing crops, outdoors, commercially, by the water-culture method. What crops, if any, could be grown profitably by this method would depend on the value of the crop in the market served, in relation to cost of production, which would include a large outlay for tanks and other equipment and materials, as well as special costs of supervision and operation. Thus far, no evidence is available on which to base any prediction as to future development of the water-culture method of crop

production under outdoor conditions. Before planning any investment in this field, the most careful consideration should be devoted to the economic and technical factors concerned. It seems improbable in view of the present cost of a commercial water-culture installation, that crops grown by this method could compete with cheap field-grown crops. Recently, popular journals have discussed a project for growing vegetables in tanks of nutrient solution, on Wake Island, in Mid-Pacific, to supply fresh vegetables (which constitute only a small proportion of the total food requirements) for the inhabitants of the island and for passengers of the clipper airships. This, however, is a special case, and there is no reason to assume that it has any general agricultural significance.

GROWING OF PLANTS IN WATER CULTURE BY AMATEURS

Most numerous among the inquiries for information about the water-culture method are those from persons who wish to grow plants in this way as a hobby. These persons usually seek exact directions as to how to proceed to carry on water cultures. For reasons, which, we hope, will be made clear through reading this circular, it is not possible to describe a general procedure that will insure success. Many technical difficulties may be met: character of water, adjustment of acidity of the solution, toxic substances from tanks or beds, uncertainty as to time for replenishing salts in the nutrient solution, or for changing the solution, and the like.

Why, it may be asked, do not most of these technical difficulties of the water-culture method arise when plants are grown in soil? Because in a naturally fertile soil, or one which can be made fertile by simple treatment, there occurs an automatic adjustment of many of the factors determining the nutrition of the plant.

Some amateurs have recently reported results satisfactory to themselves, with certain kinds of plants grown in water culture, and similar success can presumably be achieved by others through a fortunate combination of nutritional and climatic conditions. Yet without knowledge and control of the factors involved, no assurance can be given that success with one kind of plant at one season can be consistently repeated with other kinds of plants, or at other seasons. True, not every successful gardener has a thorough training in plant and soil science, nor can such training, by itself, always insure success in gardening. However, since the growing of plants in soil is one of the oldest occupations of mankind, the gardener can often obtain guidance based on a rich store of accumulated experience. Such experience is lacking for the growth of plants by the water-culture method.

In any case, growing of plants as a hobby, in either soil or culture solution, without regard to cost of labor and materials, is, of course, a

very different matter from producing crops for profit. The experience of the amateur gardener, whether he uses soil or the water-culture method, is not adequate preparation for commercial crop production.

USE OF PREPARED SALT MIXTURES

Many amateurs have become interested in the purchase of mixtures of nutrient salts ready for use, and various individuals and firms have offered for sale small packages of salt mixtures. Clearly a prepared salt mixture does not obviate the difficulties which may be met in growing plants in water culture. Recently, some firms have made highly misleading claims for the salt mixtures they sell. The California Agricultural Experiment Station makes no recommendation with regard to any salt mixture, and the fact that a mixture is registered with the California State Department of Agriculture, as required by the law governing sale of fertilizers, implies no endorsement for use of the product. The directions given later will help the amateur to prepare his own nutrient solutions.

COMPOSITION OF NUTRIENT SOLUTIONS

Thousands of requests have been received by the California Agricultural Experiment Station for formulas for nutrient salt solutions. It is often supposed that some remarkable new combination of salts has been devised and that the prime requisite for growing crops in solutions is to use this formula. Now the fact is that there is no one composition of a nutrient solution which is always superior to every other composition. Plants have marked powers of adaptation to different nutrient conditions. If this were not so, plants would not be growing in varied soils in nature. We have already emphasized in the historical sketch of the water-culture method that within certain ranges of composition and total concentration, fairly wide latitude exists in the preparation of nutrient solutions suitable for plant growth. Many varied solutions have been used successfully by different investigators. Even when two solutions differ significantly in their effects on the growth of a particular kind of plant under a given climatic condition, this does not necessarily mean that the same relation between the solutions will hold with another kind of plant, or with the same kind of plant under another climatic condition.

Another point concerning nutrient solutions needs to be stressed. After plants begin to grow, the composition of the nutrient solution changes because the constituents are absorbed by plant roots. How rapidly the change occurs depends on the rate of growth of the plants and the volume of solution available for each plant. Even when large volumes of solutions are provided, some constituents may become depleted in a comparatively short time by rapidly growing

plants. This absorption of nutrient salts causes not only a decrease in the total amounts of salts available, but a qualitative alteration as well, since not all the nutrient elements are absorbed at the same rates. One secondary result is that the acid-base balance (pH) of the solution may undergo changes which in turn may lead to precipitation of certain essential chemical elements (particularly iron and manganese) so that they are no longer available to the plant. Also to be considered are the effects of salts added with the water (discussed later).

For these various reasons, the maintenance of the most favorable nutrient medium throughout the life of the plant involves not merely the selection of an appropriate solution at the time of planting, but also continued control, with either the addition of chemicals when needed or replacement of the whole solution from time to time. Proper control of culture solutions is best guided by chemical analyses of samples of the solution taken periodically and by observations of the crop. Further investigation will determine if successful standardized procedures requiring only limited control and adjustments can be developed for a given crop, locality, and season of the year.

The plant physiologist, in his experiments, prepares his solutions with distilled water for the purpose of exact control. The commercial grower, or the amateur, is usually limited to the use of domestic or irrigation water which contains various salts, including sodium salts, such as sodium chloride, sodium sulphate, and sodium bicarbonate, as well as calcium and magnesium salts. Most waters suitable for irrigation or for drinking can be utilized in the water-culture method, but the adjustment of the reaction (pH) in the nutrient solution depends on the composition of the water. Some waters may contain so much sodium salt as to be unfit for making nutrient solutions. Even with a water only moderately high in salt content the salt may concentrate in the nutrient solution with possibly unfavorable effects on the plant, if large amounts of water have to be added to the tanks and the solutions are not changed. Also we have had experience with a well water which was highly toxic because it contained too high a concentration of zinc, apparently derived largely from circulation through galvanized pipes. The water was, however, not injurious to tomato plants when used on a soil, because of the absorbing power of the soil for zinc.

As already indicated, the successful growth of a crop is dependent on sunlight and temperature and humidity conditions, as well as on the supply of mineral nutrients furnished by the culture medium. Complex interrelations exist between climatic conditions and the utilization of these nutrients. The relation of nitrogen nutrition and climatic conditions to fruitfulness has often been stressed. In some localities, deficient sunshine may prevent the production of profitable

greenhouse crops of many species in winter months no matter what nutrient conditions are present in the culture solution.

NUTRIENT REQUIREMENTS OF DIFFERENT KINDS OF PLANTS

The question is frequently asked: Does each kind of plant require a different kind of nutrient solution? The answer is that if proper measures are taken to provide an adequate *supply* of nutrient elements, then many kinds of plants can be grown successfully in nutrient solutions of the same initial composition (the same fertile soil can produce high yields of many kinds of plants).

The composition of the nutrient solution should always be considered in relation to the total supply as well as the proportions of the various nutrient elements. To give a specific illustration: assume that several investigators prepare nutrient solutions of the same formula, but one uses 1 gallon of the solution for growing a certain number of plants, another 5 gallons of solution, and still another 50 gallons of solution. If plants were grown to large size, each investigator would reach a different conclusion as to the adequacy of the nutrient solution employed, although the initial composition was the same in all cases. The investigator using the small volume might find that his plants became starved for certain nutrients, while the one using the larger volume experienced no such difficulty. In fact, the precise initial composition of a culture solution has very little significance, since the composition undergoes continuous change as the plant grows and absorbs nutrients, and the rate and nature of this change depends on many factors, including total supply of nutrients. Adequacy of supply of nutrients involves volume of solution in relation to the number of plants grown, stage of growth of the plant and rate of absorption of nutrients, and frequency of changes of solution.

Apart from the question of adequate supply of nutrients, there are certain special responses of different species of plants which have to be taken into account in the management of nutrient solutions. Plants vary in their tolerance to acidity and alkalinity. They also differ in their susceptibility to injury from excessive concentrations of elements like boron, manganese, copper, and zinc. Some plants may be especially prone to yellowing because of difficulty in absorbing enough iron or manganese. Some may succeed best in more dilute nutrient solution than is employed for most kinds of plants. Unfavorable responses by certain plants to high nitrogen supply, in relation to fruiting, under certain climatic conditions, may require consideration.

Since the adaptation of a nutrient solution to the growth of any particular kind of plant depends on the supply of nutrients and on climatic conditions, there is no possibility of prescribing a list of

nutrient solutions, each one best for a given species of plant. Some general type of solution such as those described in this circular, should be tried first and modified later if necessary as a result of experimentation.[11]

INSECT ATTACKS AND DISEASES

Contrary to some statements, it is not true that plants grown by the water-culture method are thereby protected against disease (except strictly soil-borne diseases) or the attacks of insects. Recent observations suggest that diseases peculiar to the water-culture method may sometimes attack plants grown in nutrient solutions.

WATER REQUIREMENTS OF PLANTS GROWN BY THE WATER-CULTURE METHOD

The use of water by plants is primarily determined by the physiological characteristics of each species of plant, extent of leaf surface, and atmospheric conditions, just as when plants are grown in soil. If a large crop is produced, either by the water-culture method or in soil, and if climatic conditions favor high evaporation of water from the plant, the amount of water used in producing the crop is necessarily large.

In a greenhouse experiment conducted in Berkeley for the purpose of comparing the growth of tomatoes in soil and water-culture media, according to actual measurement, somewhat more water was required to produce a unit weight of fruit under water-culture conditions than under soil conditions. Possibly more water was evaporated from the water surface than from the soil surface, in addition to the principal loss of water by evaporation through the plant, common to both soil and water culture. The fallacy of the idea that plants could be grown in a desert region with a fraction of the water needed to produce crops in irrigated soil is evident, assuming any reasonably good management of irrigation practices.

RÉSUMÉ OF THE WATER-CULTURE TECHNIQUE

Many types of containers for nutrient solutions have been found useful. In investigational work, 1- or 2-quart Mason jars provided with cork stoppers often serve as culture vessels (pl. 5). Sometimes 5- or 10-gallon earthenware jars have been found suitable for experimental purposes. Small tanks of various dimensions have been extensively used. For certain special investigations, shallow trays or vessels of Pyrex glass are required. The selection of a container

[11] A number of inquiries have been received regarding the culture of mushrooms. The water-culture method under discussion is unsuited to the culture of mushrooms. These plants require organic matter for their nutrition, and differ in this way from green plants, which can grow in purely mineral nutrient solutions like those described in this circular

depends on the kind of plant to be grown, the length of the growing period, and the purpose for which the plants are grown. Plate 6 shows the varied types of containers for nutrient solutions as employed at the California Agricultural Experiment Station for research purposes. Some of the smaller containers illustrated would doubtless be convenient for amateur use, but the importance of the factor of aeration of the solution should be stressed. If small containers are employed and a large root system is to be developed, it may be desirable or necessary to provide for special aeration of the culture solutions. Plants differ greatly in regard to their requirements for aeration of the root system.

For commercial water culture, long, narrow, shallow tanks have been employed. They may be constructed of wood, cement, black iron coated with asphalt paint, or other sufficiently cheap materials which do not give off toxic substances. In these tanks is placed the nutrient solution in which roots of the plant are immersed. Wire screens are placed over the tops of the tanks, or inside, above the solution. The screens support a layer of bedding of varying thickness (often 3 or 4 inches), according to the kind of plant grown (pl. 7). This technique was first suggested by W. F. Gericke.[12] The bed may be prepared from a number of inexpensive materials—for example, pine shavings, pine excelsior, rice hulls. Some materials, such as redwood shavings or sawdust, may be toxic. Seeds are planted in the moist beds, or young plants from flats are set in them with their roots in the nutrient solution. Roots may later develop not only in the solutions in the tanks, but also in the beds.

The shallowness of the tanks and the porous nature of the beds facilitate aeration of the root system—an essential factor—but as already pointed out, such aeration unsupplemented by an additional oxygen supply, does not give the best growth of all kinds of plants. Recently evidence became available that significant improvement of growth and yield of tomato plants resulted from continuous bubbling of air through the nutrient solution, although the yields from unaerated cultures were at least as large as any previously reported for water culture.

Chemically pure salts commonly employed in making nutrient solutions for scientific experiments would be too expensive for commercial practice, and a number of ordinary fertilizer salts can serve in large-scale production of crops. Recent developments in the fertilizer industry have made available cheap salts of considerable degree of purity. Some commercial salts, however, contain impurities (fluorine, for example, is commonly found in phosphate fertilizers) which may be toxic to plants under water-culture conditions.

[12] Gericke, W. F., Aquaculture: A means of crop production, Amer. Journ. Bot., vol. 16, p. 862, 1929.

DIRECTIONS FOR GROWING PLANTS BY THE WATER-CULTURE METHOD

TANKS AND OTHER CONTAINERS FOR NUTRIENT SOLUTIONS

Various kinds of tanks have been utilized for growing plants in water culture. Tanks of black iron, well painted with asphalt paint (most ordinary paints cannot be used because of toxic substances), have proved satisfactory for experimental work. Galvanized iron may give trouble, even when coated with asphalt paint, if the paint scales off.

Concrete tanks have been tried, but they may require thorough leaching before use. Painting the inside of the tank with asphalt paint is advisable. Wooden tanks will serve the purpose, if made watertight. Redwood may give off toxic substances and therefore may require preliminary leaching to remove these substances. Finally, coating with asphalt paint is desirable.

For small-scale cultures, 2- or 4-gallon earthenware crocks may be serviceable. A wire screen to hold the bedding material can be bent over the sides of the crock. But if a number of plants are to be grown to large size in such jars, the solution may require special aeration as by bubbling air through it continuously.

For demonstrations in schools, Mason jars covered with brown paper, to exclude light, can be employed (pl. 5). The jars are provided with cork stoppers in which one or more holes have been bored (sometimes a slit is also made in the cork; see fig. 1). Plants are fixed in the holes with cotton. Wheat or barley plants are very suitable for these demonstrations, since they may be grown in the jars without any special arrangements for aeration.

Other types of culture vessels are shown in plate 6.

The dimensions of tanks must be selected in accordance with the objective. One kind of tank, of moderate size, adapted to many purposes, has dimensions of 30 inches in length, 30 inches in width, and 8 inches in depth (pl. 6, *B*). A smaller tank, 30 inches long, 12 inches wide, and 8 inches deep, is convenient for use in many experiments (pl. 6, *C*). In general, shallow tanks will be found suitable. The length and width may be determined by consideration of convenience and economy. As an alternative to the porous bed, for many kinds of plants, tanks can be provided with metal or wooden covers perforated to hold corks in which plants are fixed with cotton, if adequate aeration is maintained (pl. 2).[13] (See discussion of aeration, p. 467.)

[13] A description of the construction of aerating devices for culture solutions is given by: Furnstal, A. F., and Johnson, S. B., Preparation of sintered pyrex glass aerators for use in water-culture experiments with plants. Plant Physiol., vol. 11, pp. 189–94, 1936.

When large tanks are to be used with a porous bed, a heavy chicken-wire netting (1-inch mesh), coated with asphalt paint, is fastened to a frame and placed directly over the tank to provide support for the porous bed. In constructing a frame, it is advisable to leave several narrow sections not covered with wire netting, but with wooden covers which can be conveniently removed for inspection of roots or for adding water or chemicals. The wire netting should be stretched immediately above the surface of the solution when the tank is full. Cross supports may be placed under the netting to prevent it from sagging (pl. 7). A carpenter or mechanic can design and build suitable tanks and frames, which may take many forms.

NATURE OF BED [14]

When a porous bed is to be employed, a wire screen is covered by a layer of the porous material 3 or 4 inches thick—thicker when tubers or fleshy roots develop in the bed. Various cheap bedding materials have been suggested: pine excelsior, peat moss, pine shavings or sawdust, rice hulls, etc. Some materials are toxic to plants. Redwood should usually be avoided. One type of bed which has produced no toxic effects in experiments carried on in Berkeley, with tomatoes, potatoes, and certain other plants, consists of a layer of pine excelsior 2 or 3 inches thick, with a superimposed layer of rice hulls about 1 or 2 inches thick. For plants producing tubers of fleshy roots, some finer material may possibly need to be mixed with the excelsior. This is also essential when small seeds are planted in the bed, to prevent the seeds from falling into the solution and to effect good contact of moist material with the seed. In all cases, the bed must be porous and not exclude free access of air.

If seeds are planted in the bed, it must, of course, be moistened at the start and maintained moist until roots grow into the solution below. For the development of tubers, bulbs, fleshy roots, etc., the bed should be maintained in a moist state, by occasional sprinkling. Great care should be observed to prevent waterlogging of the bed, resulting from immersion of the lower portion of the bed in the solution. This leads to exclusion of air and to undesirable bacterial decompositions.

PLANTING PROCEDURES

Seeds may be planted in the moist bed, but often it is better to set out young plants chosen for their vigor, which have been grown from seeds in flats of good loam. Some seeds (for example, cereal seeds) may also be conveniently germinated between layers of moist

[14] The general arrangement of this type of bed was described by Gericke, W. F., and Tavernetti, J. R., Heating of liquid culture media for tomato production, Agr. Eng., vol. 17, pp. 141–42, 184, 1936.

filter paper (or paper toweling), particularly if plants are to be fixed in corks and grown in jars or in tanks with perforated metal or wooden covers. The upper layers of moist paper are removed after seeds begin to germinate. The seedlings are allowed to grow on the moist bed until large enough to place in corks. An excess of water is then added to the moist paper and the young plants removed carefully so as not to damage the roots.

In transplanting from a flat of soil, the soil is thoroughly soaked with water so that the plants can be removed with the least possible injury to the roots. The roots are then rinsed free of soil with a light stream of water and immediately set out in the beds or corks, with the roots immersed in the solution. When young plants are set out in the beds, the roots are placed in the solution, and at the same time the layer of excelsior is built up over the screen. Then the layer of rice hulls is placed on top of the excelsior (pl. 7). If seeds are to be planted in the bed, the whole bed must be installed and moistened before the seed is planted.

SPACING OF PLANTS

In our experiments with tomato plants, they were set close together, in some instances 20 plants to 25 square feet of solution surface. No general advice can be offered as to the best spacing. This depends on the kind of plant and on light conditions. Individual experience must guide the grower.

ADDITION OF WATER TO TANKS

In starting the culture, the tank is filled with solution almost to the level of the lower part of the bed. As the plants grow, water will be absorbed by plants or evaporated from the surface of the solution, and the level of the solution in the tank will fall. The recommendation has generally been made that after the root system is sufficiently developed, the level of the solution should remain from one to several inches below the lower part of the bed, to facilitate aeration. However, since the solution level should not be permitted to fall very far, regular additions of water are required.[15]

As pointed out earlier, when large amounts of water have to be added to a tank, excessive accumulations of certain salts contained in the water may occur, especially if the salt content of the water is high. To avoid this difficulty, the entire solution is changed whenever the salt concentration becomes high enough to influence the plant

---

[15] Certain methods of circulating culture solutions (such as those described by J. W. Shive and W. R. Robbins, in the citation given in footnote 7, p. 468, New Jersey Agr. Exp. Stat. Bull. 636) may be convenient for maintaining a supply of water and nutrients, as well as assisting in aeration of roots. One commercial greenhouse has utilized on a large scale a method of circulating nutrient solution from a central reservoir

adversely. Should plants be injured, however, by the presence in the water of high concentrations of elements like zinc, changing solutions will not prevent injury. Because of the wide variation in the composition of water from different sources, no specific directions to cover all cases can be given.

CHANGES OF NUTRIENT SOLUTION

As the plants begin to grow, nutrient salts will be absorbed and the acidity of the solution will change. More salts and acid may be added, but to know how much, chemical tests on the solution are required. When these cannot be made, an arbitrary procedure may be adopted of draining out the old solution every week or two, immediately refilling the tank with water, and adding salts and acid, as at the beginning of the culture. The number of changes of solution required will depend on the size of plants, how fast they are growing, and on volume of solution. Distribute the salts and acid to different parts of the tank. In order to effect proper mixing, it may be well to fill the tank at first only partly full (but keep most of the roots immersed) and then after adding the salts and acid, to complete the filling to the proper level with a rapid stream of water, which should be so directed as not to injure the roots.

TESTING AND ADJUSTING THE ACIDITY OF WATER AND NUTRIENT SOLUTION

Ordinarily some latitude is permissible in the degree of acidity (pH) of the nutrient solution. For most plants a moderately acid reaction (from pH 5.0 to 6.5) is suitable. If distilled water is used in the preparation of nutrient solutions, no adjustment of its reaction is necessary. If tap water is used, a preliminary test of its reaction should be made and if the water is found alkaline, it should be acidified before adding the nutrient salts.

As already stated the reaction (pH) of the nutrient solution is subject to change as the plant grows. The reaction of the culture solution should be tested from time to time and corrected, if found alkaline.

The chemicals required for testing acidity of water or nutrient solution are:

1. *Bromthymol blue indicator.*—This can be obtained with directions for use, from chemical supply houses, in the form of solutions or impregnated strips of paper. Strips of other test papers covering a wide range of acidity are also now available on the market and may be found, by the amateur who understands their use, very convenient for adjusting the acidity of water as well as that of the nutrient solution.

2. *Sulphuric acid.*—Purchase a supply of 3 percent (by volume) acid of chemically pure grade. (Concentrated, chemically pure sul-

114728—39——32

phuric acid may be purchased and diluted to 3 percent strength, *but the concentrated acid is dangerous to handle by inexperienced persons.*) This 3 percent acid may be further diluted with water if a preliminary test indicates that only small additions of acid are required to bring about a desirable reaction.

Test the degree of acidity of a measured sample of the water or nutrient solution (a quart, for example) by noting the color of the added indicator or test paper immersed in the solution. When bromthymol blue indicator is used, a yellow color indicates an acid reaction (with no further adjustment necessary), green a neutral reaction, blue an alkaline reaction.

If the original color is green or blue, add the dilute sulphuric acid (3 percent or less in strength) slowly with stirring until the color just changes to yellow (indicating approximately pH 6). Do not add more beyond this point, since the yellow color will also persist when excessive amounts of acid are added. Record the amount of acid required.

Finally, add a proportionate amount of the acid to the water or nutrient solution in the culture tank or vessel, having first determined how much it holds.

MODIFICATION OF NUTRIENT SOLUTION BASED ON ANALYSIS OF WATER

A chemical analysis of the water to be employed in making the nutrient solution is useful. Some waters may contain so much calcium, and perhaps magnesium and sulphate, that further additions of these nutrient elements are unnecessary, or even undesirable. The objective should be to approximate the intended composition of the nutrient solution, taking into account the salts already present in the water. Since, however, considerable latitude is permissible in the composition of nutrient solutions, analysis of the water is not indispensable, unless the content of mineral matter is very high.

SELECTION OF A NUTRIENT SOLUTION

As stated before, there is no one nutrient solution which is always superior to every other solution. Among many solutions which might be employed, those described below have been found to give good results with various species of plants in experiments conducted in Berkeley, with a source of good water. Other solutions can also be used with good results.

The composition of the solutions is given in two forms: (A) by rough measurements adapted to the amateur without special weighing or measuring instruments, and (B) in more exact terms for those with some knowledge of chemistry, who have proper facilities for more accurate experimentation.

PREPARATION OF NUTRIENT SOLUTIONS: METHOD A, FOR AMATEURS

Either one of the solutions given in table 2 may be tried. Solution 2 may often be preferred because the ammonium salt delays the development of undesirable alkalinity. The salts are added to the water, preferably in the order given.

To either of the solutions, add the elements iron, boron, manganese, and in some cases zinc and copper. There is danger of toxic effect if much greater quantities of these elements are added than those indicated later in the text. Molybdenum and possibly other elements required by plants in minute amounts will be furnished by impurities in the nutrient salts or in the water, and need not be added deliberately.

TABLE 2.—*Composition of nutrient solutions.*[1] (*The amounts given are for 25 gallons of solution.*)

Salt	Grade of salt	Approximate amount in ounces	Approximate amount in level tablespoons
SOLUTION 1[2]			
Potassium phosphate (monobasic)	Technical	½	1
Potassium nitrate	Fertilizer	2	4
Calcium nitrate	do	3	7
Magnesium sulphate (Epsom salt)	Technical	1½	4
SOLUTION 2			
Ammonium phosphate (monobasic)	Technical	½	2
Potassium nitrate	Fertilizer	2½	5
Calcium nitrate	do	2½	6
Magnesium sulphate (Epsom salt)	Technical	1½	4

[1] The University does not sell nor give away any salts for growing plants in water culture. Chemicals may be purchased from local chemical supply houses, or possibly may be obtained through fertilizer dealers. Some of the chemicals may be obtained from druggists. If purchased in fairly large lots, the present price of the ingredients contained in 1 pound of a complete mixture of nutrient salts is approximately 5 to 10 cents for either solution described above.

[2] To either of these solutions, supplements of elements required in minute quantity must be added; see directions in the text.

(*a*) *Boron and manganese solution.*—Dissolve 3 teaspoons of powdered boric acid and 1 teaspoon of chemically pure manganese chloride ($MnCl_2.4\ H_2O$) in a gallon of water. (Manganese sulphate could be substituted for the chloride.) Dilute 1 part of this solution with 2 parts of water, by volume. Use a pint of the *diluted* solution for each 25 gallons of nutrient solution.

The elements in group 1 are added when the nutrient solution is first prepared and at all subsequent changes of solution. If plants develop symptoms characteristic of lack of manganese or boron, solution *a*, in the amount indicated in the preceding paragraph, may be added between changes of the nutrient solution or between addition of salts needed in large quantities.[16] But care is needed, for injury may easily be produced by adding too much of these elements.

[16] The University is not prepared to diagnose symptoms on samples of plant tissues sent in for examination;

(*b*) *Zinc and copper solution.*—Ordinarily this solution may be omitted, because these elements will amost certainly be supplied as impurities in water or chemicals, or from the containers. When it is needed additions are made as for solution *a*. To prepare solution *b*, dissolve 1 teaspoon of chemically pure copper sulphate ($CuSO_4.5H_2O$) and 4 teaspoons of chemically pure zinc sulphate ($ZnSO_4.7H_2O$) in a gallon of water. Dilute 1 part of this solution with 4 parts of water. Use 1 *teaspoon* of the *diluted* solution for each 25 gallons of nutrient solution.

(*c*) *Additions of iron to nutrient solution.*—Generally, iron solution will need to be added at frequent and regular intervals, for example, once or twice a week. If the leaves of the plant tend to become yellow, even more frequent additions may be required. However, a yellowing or mottling of leaves can also arise from many other causes.

The iron solution is prepared as follows: Dissolve 1 level teaspoon of iron tartrate (iron citrate or iron sulphate can be substituted, but the tartrate or citrate is often more effective than the sulphate) in 1 quart of water. Add ½ cup of this solution to 25 gallons of nutrient solution each time iron is needed.

PREPARATION OF NUTRIENT SOLUTIONS: METHOD B, FOR SCHOOLS OR TECHNICAL LABORATORIES

For experimental purposes, the use of distilled water and chemically pure salts is recommended. Molar stock solutions (except when otherwise indicated) are prepared for each salt, and the amounts indicated below are used.

Solution 1	*Cubic centimeters in a liter of nutrient solution*
M KH_2PO_4, potassium acid phosphate	1
M KNO_3, potassium nitrate	5
M $Ca(NO_3)_2$, calcium nitrate	5
M $MgSO_4$, magnesium sulphate	2

Solution 2	*Cubic centimeters in a liter of nutrient solution*
M $NH_4H_2PO_4$, ammonium acid phosphate	1
M KNO_3, potassium nitrate	6
M $Ca(NO_3)_2$, calcium nitrate	4
M $MgSO_4$, magnesium sulphate	2

To either of these solutions add the following solutions *a* and *b* below.

(*a*) Prepare a supplementary solution which will supply boron, manganese, zinc, copper, and molybdenum as follows:

Compound:	Grams dissolved in 1 liter of H_2O
H_3BO_3, boric acid	2.86
$MnCl_2.4H_2O$, manganese chloride	1.81
$ZnSO_4.7H_2O$, zinc sulphate	.22
$CuSO_4.5H_2O$, copper sulphate	.08
$H_2MoO_4.H_2O$ molybdic acid (assaying 85 percent MoO_3)	.09

Add 1 cc of this solution for each liter of nutrient solution, when solution is first prepared or subsequently changed, or at more frequent intervals if necessary.

This will give the following concentrations:

Element:	Parts per million of nutrient solution
Boron	0.5
Manganese	.5
Zinc	.05
Copper	.02
Molybdenum	.05

(*b*) Add iron in the form of 0.5 percent iron tartrate solution or other suitable iron salt, at the rate of 1 cc per liter, about twice a week or as indicated by appearance of plants.

The reaction of the solution is adjusted to approximately pH6 by adding 0.1 NH_2SO_4 (or some other suitable dilution).

Molar solutions.—The concentrations of stock solutions of nutrient salts used in preparation of nutrient solutions are conveniently expressed in terms of molarity. A molar solution is one containing a 1 gram-molecule (mol) of dissolved substance in 1 liter of solution. (In all nutrient-solution work, the solvent is water.) A gram-molecule or mol of a compound is the number of grams corresponding to the molecular weight.

EXAMPLE 1: How to make a molar solution of magnesium sulphate: The molecular weight of magnesium sulphate, $MgSO_4.7H_2O$ is 264.50. One mol of magnesium sulphate consists of 264.50 grams. Hence to make a molar solution of magnesium sulphate, dissolve 264.50 grams of $MgSO_4.7H_2O$ in water and make to 1 liter volume.

EXAMPLE 2: How to make a $\frac{1}{20}$ molar (0.05 *M*) solution of monocalcium phosphate, $Ca(H_2PO_4)_2.H_2O$: The molecular weight of monocalcium phosphate, $Ca(H_2PO_4)_2.H_2O$ is 252.17. Hence 0.05 mol of $Ca(H_2PO_4)_2.H_2O$ is $\frac{252.17 \text{ grams}}{20} = 12.61$ grams. Therefore, to make a 0.05 *M* solution of monocalcium phosphate, dissolve 12.61 grams of $Ca(H_2PO_4)_2.H_2O$ in water and make to 1 liter volume.

This illustrates the use of the culture-solution technique for studying the nutritional responses of lettuce plants under controlled conditions. The individual plants are supported in corks which are placed in holes drilled in the metal covers. The glass and rubber tubes carry air under pressure which is bubbled through the nutrient solution in the tanks.

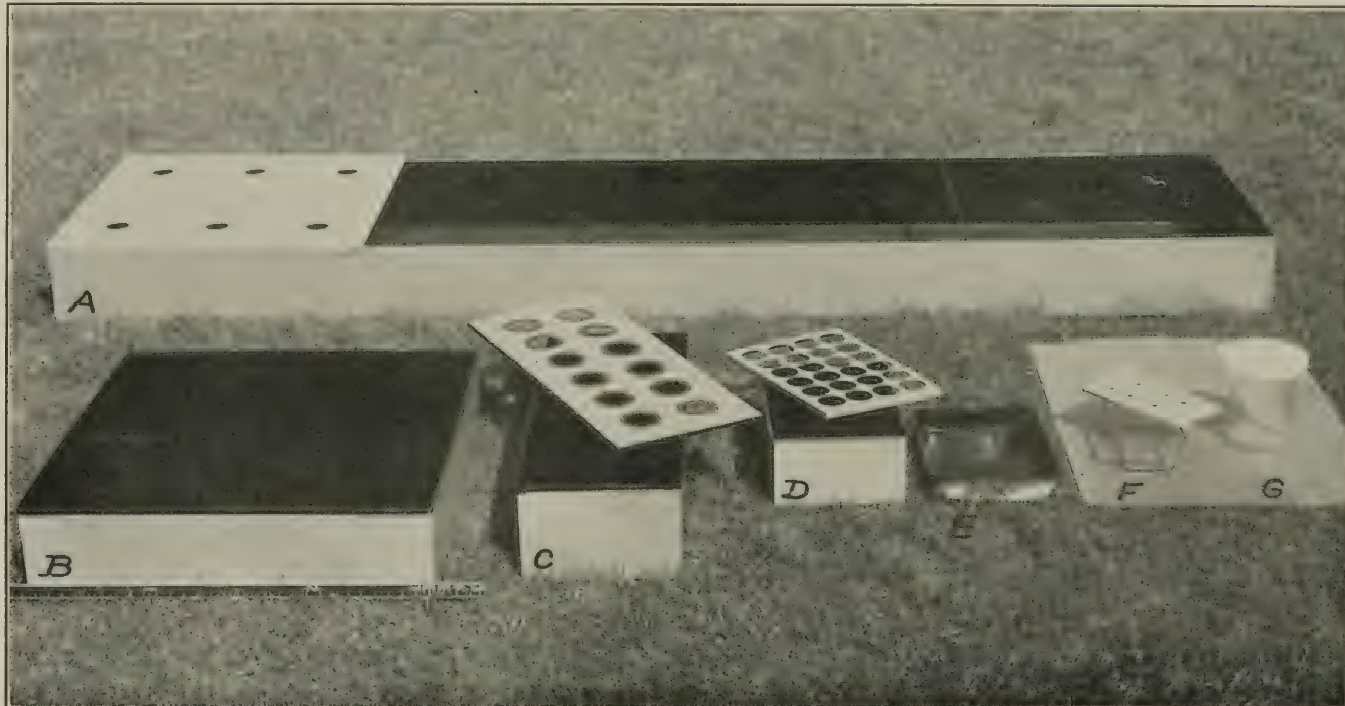
1. Effect of forced aeration on asparagus plants grown in culture solutions. *Right:* plants without forced aeration. *Left:* plants grown in solution through which air was bubbled continuously.

2. The asparagus plant on the left grew in a nutrient solution in which boron, manganese, zinc, and copper were present in such small amounts as one part in several million parts of solution; those on the right grew in solutions to which these elements were not added.

Growth of tomato plants in fertile soil, in nutrient solution, and in pure silica sand irrigated each day with nutrient solution. Fruit has been harvested for 7 weeks prior to taking the photograph. All plants have made excellent growth and set large amounts of fruit in all three media. The general cultural conditions, spacing, staking, etc., were the same.

Under favorable conditions tomato plants can grow to a great height and bear fruit over an extended period of time. This is equally possible in soil, sand, and water-culture media. The plants in the foreground were grown in a bed of fertile soil. At the time of taking this photograph, several days before the termination of the experiment, most of the fruit was already harvested.

Corn and sunflower plants grown in nutrient solution contained in 2-quart mason jars. Note method of placing plants in perforated corks. The jars are covered with thick paper to exclude light.



VARIOUS TYPES OF CONTAINERS FOR CARRYING ON EXPERIMENTS BY THE WATER-CULTURE METHOD.

A, large iron (not galvanized) tank painted inside with asphalt paint, outside with aluminum paint. Dimensions: 10 ft. × 2½ ft. × 8 in. Shows one section of metal cover. Perforated corks for supporting plants are fixed in the holes (pl. 1). Wooden frames containing bedding material may also be set over these tanks as shown in plate 7. B, iron tank of dimensions: 30 in. × 30 in. × 8 in. C, Iron tank of dimensions: 30 in. × 12 in. × 8 in. D, iron tank of dimensions: 15½ in. × 10½ in. × 6 in. E, graniteware pan 16 in. × 11 in. × 2½ in. used for growing small plants. Perforated metal covers as shown in A, C, and D may be used on all metal tanks or trays. The number of holes in the cover can be varied according to the number and size of plants to be grown. F and G, pyrex dish and beaker used for special experiments designed to study the essentiality of certain chemical elements required by plants in minute quantity, such as zinc, copper, and manganese. The covers for these containers shown in the illustration are molded from plaster of paris and then coated with paraffin.

GENERAL ARRANGEMENT OF TANK EQUIPMENT AND METHOD OF PLANTING.

Second tank from the left: A frame supporting a wire screen fits over the metal tank (pl. 6, A) filled with the nutrient solution. First tank on the left: Tomato plants are placed with their roots immersed in the nutrient solution. A layer of excelsior is spread over the netting, as shown in the far end of the tank. Third tank from the left: The planting is completed by spreading a layer of rice hulls over the excelsior.

"ROOT-PRESSURE"—AN UNAPPRECIATED FORCE IN SAP MOVEMENT [1]

By Philip R. White

[With one plate]

The long and tortuous history of our knowledge—or better our observations and theories—on the movement of sap in plants is familiar to most botanists. From the time of Stephen Hales, 200 years ago, up to the middle of the nineteenth century, the movement of water through the plant was supposed to be brought about primarily through the activity of living cells, either by the agency of unidentified tissues of root and stem, as Hales believed (1727), or the medullary rays, as suggested by Knight (1801). The "drawing power" of the leaves was recognized by both Hales and Knight, but, since it was well known that a suction pump would not lift water higher than about 30 feet, this was considered of secondary importance. Beginning about 1860, along with the rise of mechanistic theories in other fields, evidence began to accumulate which indicated that living cells might not be necessary for the rise of sap. This changing viewpoint found strong support in Molisch's demonstration (1902) of the traumatic nature of many of the bleeding phenomena upon which Hales' vital theory rested and finally culminated in the development of the Dixon-Askenazy cohesion theory of sap movement (Dixon and Joly, 1895; Askenazy, 1895). This theory, which takes account of the enormous suctions developed at evaporating leaf surfaces and of the fact that in capillary tubes water possesses a great tensile strength capable of transmitting these suctions through a plant stem to the soil, seemed to deal with forces more nearly commensurate with the needs of tall trees than had those demonstrated by Hales and his successors. The result was that most plant physiologists completely abandoned the vital theories in favor of the mechanical ones. In spite of the objections of Priestley (1935), Ursprung (1906), Heyl (1933), and others, that is approximately where the situation rests today.

The cohesion theory certainly has some very serious flaws which are rather well outlined in Priestley's paper of 2 years ago (1935). It has

[1] Paper from the Department of Animal and Plant Pathology of the Rockefeller Institute for Medical Research, Princeton, New Jersey, presented at the Indianapolis meeting of the American Association for the Advancement of Science, December 1937. The American Association prize was awarded to Dr. White for his noteworthy contribution to science presented at the annual meeting. Reprinted by permission from the American Journal of Botany, vol. 25, No. 3, March 1938.

been accepted not so much because of its freedom from objections as because of the inadequacy of all other theories. The only real contender—Hales' old "root-pressure" scheme—was rejected, first, because pressures greater than the 1.4 atmospheres recorded by Hales himself had not been observed, and, second, because all demonstrations of root-pressure rested on experiments with decapitated and moribund plants subject to Molisch's criticism. Water must be raised in some Eucalyptus trees to a height of 350 feet, requiring either a push or a pull of at least 13 atmospheres. The maximum root-pressures observed were only of a magnitude of 1.4 atmospheres, they were transitory, and doubt even existed as to their presence in uninjured plants. Consequently, modern plant physiology texts for the most part treat "root-pressure" as unimportant.

Excised roots of tomato have been kept growing in vitro for a number of years (White, 1937). The roots form normally developed vascular strands, although completely immersed in a nutrient solution (pl. 1, fig. 1). The occurrence of strands in roots grown under these conditions has seemed rather anomalous. If, however, a continuous flow of liquid be assumed to take place through the roots, the presence of strands would be understandable. If such a current exists, it was thought these roots might offer a means of determining the reality or unreality of "root-pressure" and perhaps of measuring it under conditions free from Molisch's objections.

Means have, therefore, been devised of repeating Hales' original experiment, using single actively metabolizing tomato roots instead of his moribund grapevine stocks.

Capillary manometers were built to receive single roots. Specimens of a clone of excised tomato roots grown in continuous culture for the past 5 years were subcultured and allowed to stand for 1 week, to give the cut surfaces time to heal completely. Their bases were then carefully inserted into manometers, and seals were made by means of miniature rubber hose corresponding to those used in the classic *Fuchsia* demonstration known to every student of plant physiology. The roots with their attached manometers were returned to fresh flasks of nutrient, and their subsequent behavior observed (pl. 1, fig. 2). All manipulations had, of course, to be carried out aseptically and with as little trauma as possible.

The results of the first experiments were surprisingly good (White, 1936). The roots did secrete water from their bases into manometers. There does exist a unidirectional flow of liquid through these roots. "Root-pressure" is not an artifact but a reality. This paper proposes to present some quantitative results of these experiments.

If roots of this kind are set up in two series of manometers, with capillaries of the same diameter, one series containing water, the other mercury, we would expect a decrease in the secretion rate under the

mercury column corresponding to the 13.5:1 differential in weight between mercury and water. Figure 1 shows the result of such an experiment using manometers 500 mm high. Contrary to expectation, no such observable decrease occurred. Both columns rose at the same rate. The pressure differential apparently had no effect on the secretion rates. The only conclusion to be drawn is that the curves do not represent pressures at all but only volumes.

Closed manometers in which the pressure would build up rapidly with very little volume change were tried, but such manometers proved hard to clean and did not permit the detection of leaks at the root-manometer juncture. Leveling bulbs were then resorted to. Results

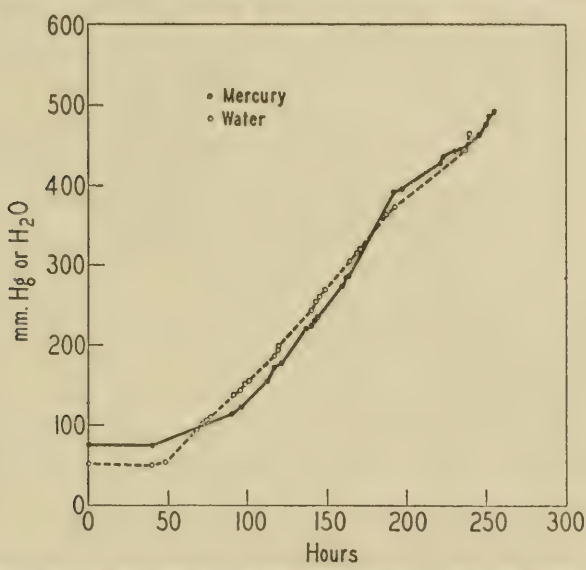


FIGURE 1.—Curves showing rise of liquid in two similar manometers, one filled with water, the other with mercury. The roots failed to secrete during the first 48 hours after the experiment was set up, presumably until they had recovered from the shock of manipulation. This lag does not always occur. The curves have almost identical slopes in spite of the 13.5:1 differential in weight between mercury and water.

of an experiment with such a device are represented in figure 2. During the course of the experiment it was thrice necessary to replace or extend the manometer tube, and since the tubes were not all of the same diameter, a different scale had to be used for each. Scales were chosen, such that the slope of the curve for an hour or so before and after each change should be approximately the same. In this experiment the water column rose 1,790 mm in 6 days. A leveling bulb was then attached, and an atmosphere of pressure—760 mm Hg—was applied. Since the column continued to rise at an undiminished rate, the pressure was increased after 20 hours to 2 atm. (1,520 mm Hg). The water still continued to rise. Sufficient mercury to give another atmosphere of pressure would have carried the bulb through

the ceiling of the room, so the apparatus was carefully moved to a nearby laboratory which had a stairway in it, and the bulb was carried into the room above. Unfortunately, a period of adjustment was not allowed, as should have been done, so that when, under 3 atmospheres pressure, the column began to fall, no definite cause could be assigned

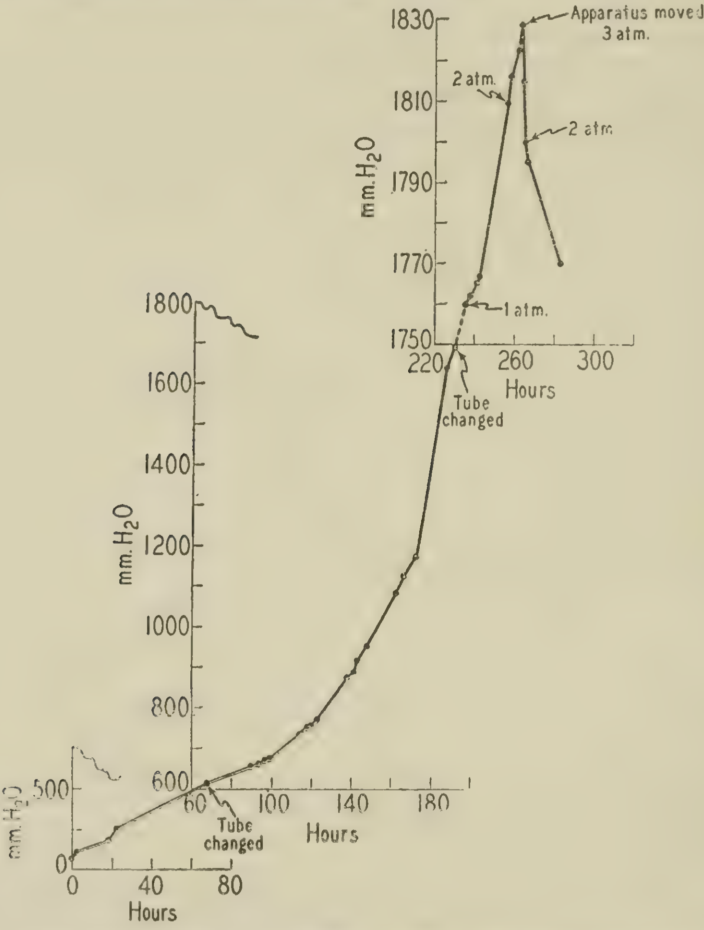


Figure 2.—A curve showing the effect of imposing pressures up to 3 atm. against the secretion pressures developed by a single tomato root.

for the drop. But the fact that when the pressure was reduced again to 2 atm., the column did not resume the upward course it had previously held at that pressure, indicated that a leak in the apparatus had probably been brought about in moving. The important fact demonstrated by this experiment is that a pressure of 2 atm. was not sufficient to retard noticeably secretion of water from the uninjured base of a single root of tomato.

Since roots of this sort developed pressures in excess of 30 pounds to the square inch, it was evident that something more than the simple hose seal between glass and root would have to be devised to stand the pressures. After many trials, the assembly shown in plate 1, figure 3, was developed. The base of the manometer had a hole about 1 mm in diameter and 15 mm deep to receive the base of the root. Above this the opening tapered abruptly to a bore of about 0.25 mm. A centimeter back of the tip on the outside was a collar of glass. The specially made rubber connecting tube had a corresponding collar inside, with the hole about 1.5 mm in diameter at the end which was to fit over the glass and only about 0.1 mm in diameter where it was to enclose the root. In setting up an experiment, this tube was moistened with glycerine and the end of the manometer inserted completely through it so that the tip protruded. The base of the root was then inserted into the manometer and the rubber pushed back until it enclosed the root for a distance of about a centimeter and the glass for an equal distance. A strong linen thread was bound tightly around the rubber both over the root and over the glass. The rubber distributed the pressure so that this binding did not crush the root, while the glass collar prevented the rubber from slipping off. The whole was then enclosed in a metal clamp, which had collars to press into the rubber at both ends. This effectively protected the rubber from being ruptured by the pressures applied. The manometer was then inserted into a 500 ml Erlenmeyer flask and the upper end attached to a metal manifold. Pressure was applied to the manifold from a compressed air tank and observation begun. The manifold used took 4 manometers at a time.

In the first series of experiments with this apparatus, a gage reading to 100 pounds per square inch was used, on the supposition that this would suffice to record any pressure obtained. Figure 3 represents the results of one experiment with such a setup. The rise of the water column was observed for 24 hours and the secretion curve, which showed a definite diurnal variation in slope,[2] plotted. Pressure of one atmosphere was applied at 4 p. m. and, since the column continued to rise, a second atmosphere was applied at 5 p. m. and the apparatus left over night. Under a pressure of 2 atm. the column rose as rapidly that night as it had in the corresponding period of the

[2] This diurnal rhythm was observed in all experiments where readings were made at frequent enough intervals to permit its detection. It seems to be a regular characteristic of the secretion process. The roots used were not protected against the diurnal variations in temperature (24°-28° C., June 1936) and illumination characteristic of a laboratory room with NE. exposure. Nevertheless, since the mean daily temperatures often varied more than did the hourly temperatures within single 24-hour periods, without producing corresponding variations in secretion rate, it seems improbable that this rhythm is the result of temperature variations. It is difficult, though not impossible, to imagine how an organ without chlorophyll and whose growth rate has been shown to be independent of illumination of the intensity obtained in the laboratory (White, 1937) could have this one process so markedly affected by illumination. This diurnal rhythm remains an interesting but as yet unexplained feature of the secretion process.

day before, so at 9 a. m. the pressure was increased to 3 atm., at 11 a. m. to 4 atm., at 2 p. m. to 5 atm., and at 4 p. m. to 6 atm. At 7 o'clock that evening the column was still rising, and by 9 the next morning had risen an additional 110 mm, although it had been subjected to a pressure of 90 pounds per square inch over that period. As already stated, the gage read only to 100 lbs. Another atmos-

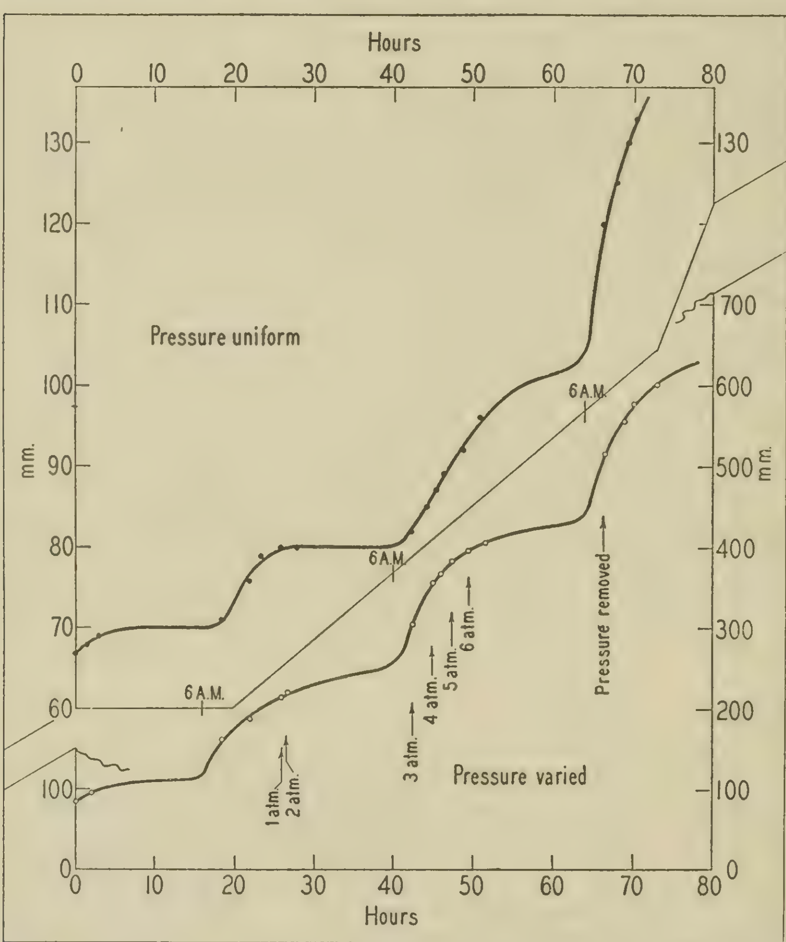


FIGURE 3.—Curves showing the rates of secretion of two similar tomato roots over a period of 3½ days, one with uniform (atmospheric) pressure, the other against imposed pressures up to 90 lbs./sq. in.

phere would have given a pressure of 105 lbs., so the attempt to reach a pressure sufficient to stop secretion had to be abandoned. The pressure was, therefore, removed and the remainder of the curve to the top of the manometer plotted. A control curve, obtained without imposed pressure, is plotted above the experimental one, for comparison.

If, now, the control curve, recorded without imposed pressure, is compared with the experimental one, obtained under pressures varying between 0 and 6 atm., they are seen to be almost exactly alike. Moreover, if the segment: 9 a. m. to noon, on the 3d day, is compared with the corresponding segment on the 4th day, their slopes are seen to be almost identical, although the second was obtained under zero pressure and the first under 3 atm. This record represents one of 4 manometers set up in series on a single manifold. A second gave an identical curve up to the afternoon of the 3d day when a bacterial contamination of the culture solution set in and secretion stopped abruptly. A third gave a similar curve but with a shallower slope, possibly because the root used had a smaller diameter, and the fourth developed a leak around the root which permitted air to escape. Six atmospheres pressure, 4 times the greatest value that I have found recorded elsewhere for root-pressure (the exudation pressures of Boehm, Figdor, Molisch, and MacDougal were of quite a different sort, in that they were obtained as a result of trauma) was not enough to slow down secretion to a measurable extent.

The sap movement which we are here studying is a matter of filtration through a membrane which we usually assume to be readily permeable to water, and surely equally permeable in either direction. The membrane can, therefore, be ignored in any calculation of the forces causing filtration, at least so long as movement is slow. We have been trying to balance a measured applied force against an unknown secretion force. Secretion should stop when the external and internal forces are equal, and water should flow back through the membrane—the root—when the applied force exceeds the force of secretion. Secretion should become slower and slower as the external force approaches the value of the internal one.

Six atmospheres external pressure did not bring about any observable retardation of secretion from these roots. Only one conclusion appears possible from this observation—6 atmospheres must be so small in comparison with the secretion pressure actually developed by the roots as to be quite insignificant. It is the writer's opinion that this secretion pressure cannot be less than 10 atmospheres and is probably much more than that. In fact, it seems possible that it may be limited only by the osmotic value of the cells themselves. Attempts have been made to impose still higher pressures, but they have met with mechanical difficulties that have not yet been overcome. It is interesting that so far failures have all been due to flaws in the apparatus. The roots have not failed to secrete liquid regularly against all pressures to which they have been subjected.

The old "root-pressure" theory of Hales has been disparaged by modern plant physiology texts because it did not provide sufficient force and because of the suspicion that it might be an artifact. These

experiments seem to show conclusively that both objections are invalid. "Root-pressure" is certainly a very real phenomenon, going on in uninjured normally metabolizing roots and showing a striking diurnal rhythm that is reminiscent of many vital processes. The fact that a bacterial contamination will stop secretion so suddenly indicates the metabolic character of the process. And the force developed is of a magnitude not to be despised. Six atmospheres pressure is sufficient to sustain a 200-foot water column. This is far higher than any tomato plant ever grows. Yet such a column appears to be small in comparison with what the lifting power of tomato roots is capable of sustaining. That is a force which is to be reckoned with. It has been unappreciated in the past because, before the development of the root-culture technique, only moribund and abnormally metabolizing tissues could be studied.

It is not suggested that mechanical factors, such as transpiration-pull, cohesion, capillarity, etc., do not play a considerable role in sap movement. Under conditions of high transpiration they probably do account for the movement of large volumes of water through the plant. It is merely pointed out that under certain conditions—such as those prevailing in the spring when the maple sap is flowing, though leaves have not been developed—some or all of these mechanical processes cease to function. At such times root-pressure or its equivalent, stem-pressure, is quite adequate to provide for the proper functioning of even the tallest trees.

No attempt will be made at present to explain how this force is developed. It may be said, however, that we are much interested in determining if there is a diurnal rhythm in respiration rate to correspond with the observed rhythm in rate of secretion. It will take some rather delicate methods to determine that. But it is believed that we have here a phenomenon which can be studied in detail and which may throw some light on the mechanism of secretion

SUMMARY

Experiments have shown that excised tomato roots growing in vitro secrete sap continuously and rhythmically from their proximal ends. Methods of measuring the force of this secretion have been developed. It is not retarded by opposed pressures of 90 pounds per square inch. The secretion force, therefore, probably greatly exceeds this value. Since a pressure of 90 pounds per square inch is sufficient to raise water to a height of 200 feet, and since the existence of such secretion pressures has been demonstrated in normally metabolizing, actively growing roots, it is concluded that "root-pressure" may be a far more important factor in sap movement than has been generally conceded.

REFERENCES

Askenazy, E.

1895. Ueber das Saftsteigen. Verh. natur. med. Ver. Heidelberg, n. f., vol. 5, pp. 325–345.

Dixon, H. H., and Joly, J.

1895. On the ascent of sap. Phil. Trans. Roy. Soc. London, B 186; pp. 563–576.

Hales, S.

1727. Vegetable staticks, or an account of some statical experiments on the sap in vegetables. J. Peele, London.

Heyl, J. G.

1933. Der Einfluss von Aussenfaktoren auf das Bluten der Pflanzen. Planta, vol. 20, pp. 294–353.

Knight, T. A.

1801. Account of some experiments on the ascent of the sap in trees. Phil. Trans. Roy. Soc. London, B 1801, pp. 333–353.

Molisch, H.

1902. Ueber localen Blutungsdruck und seine Ursachen. Bot. Zeit., vol. 60, pp. 45–63.

Priestly, J. H.

1935. Sap ascent in the tree. Science Progress, vol. 117, pp. 42–56.

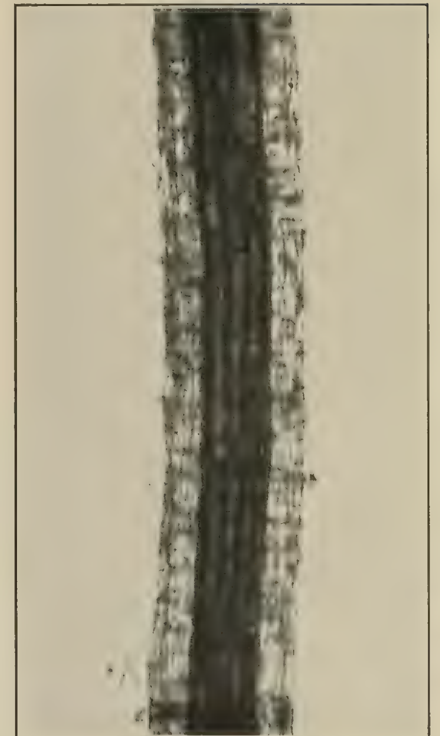
Ursprung, A.

1906. Die Beteiligung lebender Zellen am Saftsteigen. Jahrb. Wiss. Bot., vol. 42, pp. 503–544.

White, P. R.

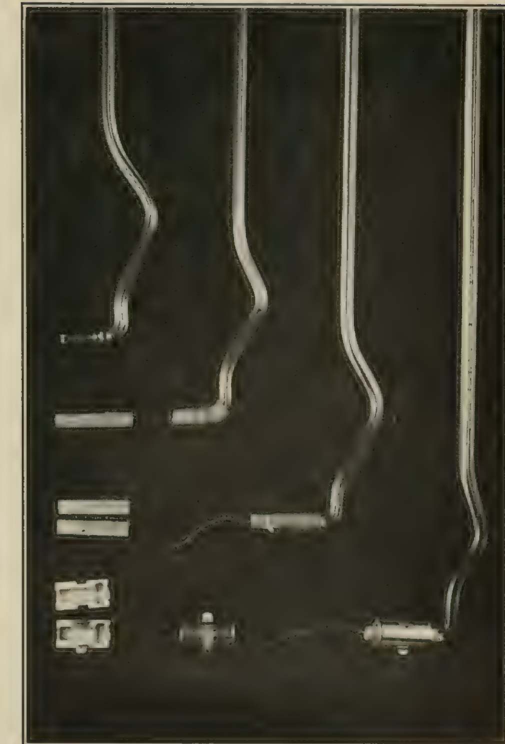
1936. Root-pressure developed in isolated tomato roots growing in vitro. Paper presented before Amer. Soc. Plant Physiol., Atlantic City, Dec. 1936.

1937. Seasonal fluctuations in growth rates of excised tomato root tips. Plant Physiol., vol. 12, pp. 183–190.



1. Root of tomato (*Solanum lycopersicum* L.) (246th passage in vitro) showing the well-developed vascular strand. × 90. (Photograph by J. A. Carlisle.)

2. Tomato root with attached manometer. (Photograph by J. A. Carlisle.)



3. Assembly, consisting of glass manometer, rubber connecting tube, and metal clamp, by which a single tomato root can be attached to a recording apparatus and its secretion forces measured. (Photograph by J. A. Carlisle.)

THE REPRODUCTION OF VIRUS PROTEINS[1 2]

By W. M. Stanley

Department of Animal and Plant Pathology of The Rockefeller Institute for Medical Research, Princeton, N. J.

Protoplasm is the stuff of life. It has, for some time, been regarded as living matter in its simplest form. It has interested biologists for over 100 years, and has been the subject of extensive physical and chemical studies. However, the present state of our knowledge of protoplasm is best attested to by the fact that we are gathered here in a symposium on the very nature of this material. We know much about protoplasm, yet we do not know what it really is. There is a vital difference between the grayish, translucent, slimy protoplasm which is the slime molds and the grayish, slimy material of certain protein gels, yet we do not know exactly what constitutes this vital difference. Biologists have, for many years, attempted to differentiate between the living and the nonliving in protoplasm, without much success. According to Seifriz, many of the older ideas have been discarded and the discussion has settled down to the question as to whether a vital substance is concerned or whether protoplasm results from a certain combination of substances, themselves nonliving. Most of the workers appear to feel that life results from a certain combination of a number of constituent parts, but that if a single vital substance is essential it is probably a protein or protein complex. Since viruses have long been considered to be living organisms and since certain typical viruses have been isolated recently in the form of high molecular weight proteins, it is obvious that a careful consideration of the nature of these virus proteins may throw some light on this question.

Viruses are of unusual interest in this connection, because with respect to size they bridge the gap between the living and the nonliving. At the upper end of a scale (see fig. 1) which includes entities ranging in size from the molecule of egg albumin, through viruses, up

[1] Read at a symposium of the American Society of Naturalists in joint session with the American Society of Zoologists, the Botanical Society of America, and the Genetics Society of America. The American Association for the Advancement of Science, Indianapolis, Ind., December 30, 1937. Reprinted by permission from The American Naturalist, vol. 72, No. 739, March-April 1938.

[2] The writer wishes to thank the many individuals who have contributed to the development and clarification of several of the points discussed in this paper.

114728—39——33

COMPARATIVE SIZES OF VIRUSES

	Molecular weight X 10^{-6} (Particle weight X6.06 X 10^{17})	Diam. or length X width in $m\mu$	
Red blood cells*	173 000 000	7 500	
Bacillus prodigiosus*	173 000	750	
Rickettsia*	11 100	300	
Psittacosis*	8 500	275	
Vaccinia*	2 300		
Myxoma*	2 300	175	
Canary pox*	2 300		
Pleuro-pneumonia organism*	1 400		
Pseudo rabies	1 400	150	
Ectromelia	1 400		
Herpes simplex	1 400		
Rabies fixe'	800	125	
Borna disease	800		
Influenza	700	120	
Vesicular stomatitis	410	100	
Staphylococcus bacteriophage †	300	90	
Fowl plague	300		
C_{16} bacteriophage	173	75	
Chicken tumor I *	142	70	
Tobacco mosaic*	43	430 X 12.3	
Cucumber mosaics 3 and 4 *	43		
Gene (Muller's est. of max. size) *	33	125 X 20	
Latent mosaic of potato*	26	430 X 9.8	
Rabbit papilloma (Shope)*	25	40	
Equine encephalitis	23	38	
Megatherium bacteriophage	23		
Rift valley fever	11	30	
Tomato bushy stunt*	9	28	
Tobacco ring spot*	7.4	26	
Hemocyanin molecule (Busycon)*	6.7	59 X 13.2	
Yellow fever	4.3	22	
Louping ill	2.8	19	
Hemocyanin molecule (Octopus)*	2.8	64 X 8	
Poliomyelitis	0.7	12	
Staphylococcus bacteriophage†	0.4	10	
Foot-and-mouth disease	0.4		
Hemoglobin molecule (Horse)*	0.069	2.8 X 0.6	1/10th these sizes
Egg albumin molecule*	0.040	1.8 X 0.6	

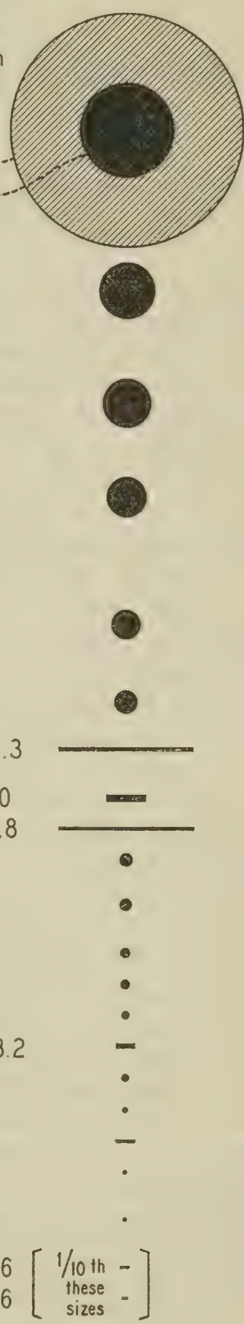


FIGURE 1.
(Explanatory matter on opposite page.)

to the red blood cell, it may be seen that certain viruses such as vaccinia and psittacosis are larger than certain well-recognized organisms such as the pleuro-pneumonia organism. At the lower end of the scale certain viruses such as poliomyelitis and yellow fever viruses are smaller than certain protein molecules. Viruses, therefore, form an unbroken line with respect to size from the molecules to the organisms, and it is impossible at present to draw a dividing line between the two. Now, let us examine the nature of these agents. I have said that certain viruses have been isolated in the form of high molecular weight proteins, and we know that others have been isolated in the form of heavy materials composed chiefly of protein. The ones so isolated include those of foot-and-mouth disease, the staphylococcus bacteriophage, latent mosaic of potato, tobacco ring spot, severe etch, cucumber mosaic, many strains of tobacco mosaic, the Shope papilloma, coli-bacteriophage, the Rous fowl sarcoma, vaccinia and psittacosis. Many of these have been isolated in such small amounts that it has been impossible to study them adequately, hence it is not known whether or not they really have the ordinary properties of molecules. It is possible that some are not molecules, but molecular aggregates or even small specialized organisms. Methods are now available for the preparation in adequate amounts of most of these entities, hence it is but a question of time until sufficient amounts for complete studies are prepared. However, certain of the virus proteins, notably tobacco mosaic, have been prepared in such large amounts that rather complete physical, chemical, biological, and serological studies have been possible. These studies have enabled a rather good yet still incomplete understanding of the probable nature of this virus protein. This afternoon I should like to discuss certain aspects of these studies which may be of value to us in understanding a bit about the manner in which protoplasm grows.

Tobacco mosaic virus was first isolated in the form of a high molecular weight crystalline protein early in 1935. The material first isolated was not homogeneous in all respects, but since that time it has been possible to prepare tobacco mosaic virus protein that is homogeneous with respect to its physical, chemical, biological, and serological properties. I should like to dwell upon this last statement regarding the homogeneity of the virus protein only sufficiently to impress upon

---

A chart showing the relative sizes of several selected viruses, including bacteriophages, as compared to those of red blood cells, *Bacillus prodigiosus*, rickettsia, pleuropneumonia organism, and protein molecules. The figures for size have been arbitrarily selected from data available in the literature. Particles known to be asymmetric are so indicated and the estimated length and width and the molecular weight in accordance with the asymmetry are given. In other cases where the particles are known or assumed to be spherical, the diameter and the molecular weight based on a sphere of density 1.3 are given. *=evidence regarding shape available. †=large size from filtration and sedimentation of concentrated solutions and small size from diffusion of dilute solutions. (This figure, which is an enlarged and revised version of the one originally accompanying this article, is taken from W. M. Stanley, Recent advances in the study of viruses, *in* Science in Progress, 1939, Yale University Press, New Haven.)

you that, according to all the tests that we have been able to devise, the protein is homogeneous in all respects, hence pure, hence is the virus. Among the physical tests that have been used is homogeneity with respect to rate of sedimentation, as measured in the Svedberg ultracentrifuge, and homogeneity with respect to electrochemical behavior, as measured in the electrophoresis cell. Chemical tests for homogeneity include fractionation of the protein by fractional crystallization and by centrifugation from solution under a variety of conditions, solubility studies, correlation of absorption spectrum with destruction spectrum and studies on partial inactivation. The biological tests include the determination of the virus activity of the various fractions of protein obtained by physical and chemical means. The serological experiments include precipitin, complement-fixation, and both *in vitro* and *in vivo* anaphylactic tests. In connection with these tests, you may recall that at the meetings a year ago the protein as then prepared showed a cross reaction with normal plant protein when tested by the very sensitive anaphylactic technique. It was suggested that this cross reaction might be due to the presence of a fraction of a percent of normal protein as an impurity. This has been found to be the case, and it is now possible to remove this impurity and to prepare protein that gives no cross reaction with other material even by the most sensitive serological tests. Thus, by all the tests that we have been able to devise, the tobacco mosaic virus protein appears to be homogeneous. There is always the possibility, of course, that the virus activity is not due to the high molecular weight protein but to an impurity that cannot be detected by means now at our disposal. It should be recognized, however, that, by virtue of the experimental evidence for homogeneity already available, an impurity could hardly be other than a closely related high molecular weight protein, hence it would still follow that the virus is a protein. The possibility that the activity may be due to an impurity must always remain, regardless of the material under discussion. However, since there is no reason to believe that such a situation actually prevails in the case of the virus protein, we are unable, at the present time, to conclude other than that the high molecular weight protein under discussion is the virus. Now, these same tests that indicate that the virus protein is homogeneous may be used to demonstrate that it possesses the ordinary properties of molecules. As a matter of fact, the chemist, after a perusal of the physical and chemical properties of tobacco mosaic virus protein, has no difficulty whatsoever in coming to the conclusion that, despite its huge size, it has all the properties of a molecule and hence is a molecule.

However, we must remember that in addition to the properties which tobacco mosaic virus protein possesses as a molecule it also

possesses virus activity, and the essence of virus activity is reproduction. It is this property of the virus proteins that may give us a lead in our consideration of the growth of protoplasm and in which we are especially interested this afternoon. Let us examine the facts that we have at our disposal. The introduction of a few molecules or perhaps even one molecule of tobacco mosaic virus protein into the cell of a susceptible host is followed by the production within a very short time of millions of molecules of the kind introduced. The production is not confined to the one cell but spreads to adjoining cells, so that not one cell but millions of cells are involved in the production of the new molecules of virus protein. We know that the new virus protein is of the same kind as that originally introduced, because we can isolate it and compare its properties with the properties of the virus protein introduced. We say that under such conditions the virus protein grows or reproduces, for from a few molecules we secure millions of molecules. Now, what happens when we retain the virus protein in a test tube or attempt to culture it on cell-free media or introduce it into dead cells or the cells of nonsusceptible hosts? We know that nothing happens, the amount of the protein does not increase, reproduction does not occur. Viruses have been found to reproduce, therefore, only within the living cells of certain susceptible hosts. I have said that in such cells the introduction of one kind of molecules results in the production of millions of the same kind. This is true, but it is not the whole truth, for just as there is this remarkable tendency for the production of millions of molecules of the same kind, there is also a remarkable tendency for the production of a very few slightly different molecules. The subsequent reproduction of such slightly different molecules gives rise to what we call a new strain, and the whole phenomenon may be regarded as mutation. We recognize that such a change has occurred by the symptoms we observe and because it is possible by suitable technique to isolate such strains. Thus Jensen has been able to isolate from a pure strain of tobacco mosaic virus over 50 strains, each of which he considers to be different and distinctive, and Holmes has been able to isolate a strain of tobacco mosaic virus that is so mild in its effect on the Turkish tobacco plant that it is difficult to determine its presence by mere observation. It might be argued that these various strains existed in the so-called pure strain as contaminants, but all the evidence obtained by Jensen, Kunkel, Holmes, and McKinney indicates that the new strains arise from a single pure strain when reproducing within the plant cells. We may conclude, therefore, that tobacco mosaic virus protein may reproduce within the cells of certain hosts and that when it does it tends to mutate and to give rise to new strains. Now, this ability to reproduce and to mutate only when within the living cells of certain

hosts is a property that we have not hitherto ascribed to ordinary molecules. We know, of course, certain autocatalytic reactions, such as the conversion of trypsinogen into trypsin *in vitro* on the addition of a little trypsin, in which a protein molecule appears to be reproducing itself, yet we also know that in such instances the precursor is chemically quite similar to the end product. The situation prevailing in the case of tobacco mosaic virus appears to be different, for here we have found no evidence for the existence of a precursor similar to the virus protein and the reaction has so far been carried out only within living cells. Despite the fact that the net result of virus reproduction may be regarded as similar to that of an autocatalytic reaction, there is at this time no precedent for regarding the reaction itself as a true autocatalytic reaction. I feel that it is better to admit our ignorance, as long as we are forced to the inside of a living cell to achieve a set of conditions in which to conduct our autocatalytic reaction. It is a fact that we do not know all that goes on within a living cell and, despite many attempts to duplicate it or the set of conditions prevailing within, we have been unsuccessful. We are forced to conclude, therefore, that, although tobacco mosaic virus protein has the ordinary properties of molecules, it also has the ability to reproduce and to mutate, properties not ordinarily ascribed to molecules, and hence that tobacco mosaic virus protein represents an entity unfamiliar to us. Now, we may speculate concerning its nature and the manner in which it reproduces and mutates. I wish to impress upon you that this portion of the discussion is not based upon fact, but upon fancy.

Let us first consider whether tobacco mosaic virus differs from ordinary living organisms. The fact that it has proved impossible to cultivate tobacco mosaic virus in the absence of living cells is frequently cited as evidence that it differs in nature from ordinary living organisms. However, this property of obligate intracellular parasitism is not peculiar to viruses, for there are certain organisms that are known to be obligate parasites and to require the presence of living cells for reproduction. I do not feel, therefore, that our failure to cultivate viruses on synthetic media necessarily means that they differ from bacteria. The fact that tobacco mosaic virus protein may by crystallized has also been cited as evidence that it is not a living organism. Yet we know that crystallization is merely orientation and that orientation occurs in many living systems. Stretched muscle is orientated and gives an X-ray diffraction pattern that is characteristic of the crystalline state. At certain stages of cell division orientation occurs within the nucleus, for it becomes highly doubly refractive. I do not feel, therefore, that the fact that we can cause tobacco mosaic virus protein to line up in orderly fashion need necessarily mean that it is nonliving. No evidence has been obtained that viruses have cell walls, and this might be used as a basis for estab-

lishing a difference were it not for the fact that the slime molds appear to grow without well-differentiated cell walls. The absence of a cell wall, therefore, need not necessarily mean that tobacco mosaic virus is nonliving. Tobacco mosaic virus protein appears to possess a definite solubility, and it might be expected that this might be used as a distinguishing characteristic. However, if an organism were sufficiently small you might expect it to be governed by the ordinary laws of physics and chemistry. Furthermore, this property is relative, for if you move your point of reference to the inside of a whirling centrifuge the virus protein loses this property and settles out as would any bacterial suspension. Another point that may be considered is respiration, for it is well known that nobody has been able to demonstrate that viruses respire, whereas it is usually possible to show that living things respire. However, even this point fails us, for we know that it is difficult, if not impossible, to demonstrate respiration in the cases of some living things, such as certain seeds or bacterial spores. It is obvious that we can take up the supposed differences and eliminate them one by one when considered individually. However, when we consider these differences collectively, one is not quite so certain, and I think you will agree with me that there is a tendency for a reasonable doubt as to whether viruses are really similar in all respects to organisms. This doubt becomes even stronger when we consider one additional factor, namely, the size of viruses. I have already pointed out that certain viruses are smaller than accepted protein molecules. We have always assumed that a certain degree of complexity was necessary for life. In its simplest form this complexity might conceivably be represented by the interplay of a very few, perhaps even two, molecules. It may appear very questionable whether or not the degree of complexity characteristic of living organisms can be woven into a single molecule. However, argument based on size alone is not valid over the whole range, for, if we consider vaccinia virus a molecule, we know that into an entity of the same size can be woven the degree of complexity under discussion, for the pleuro-pneumonia organism is just such an entity. Nevertheless, I think there must be a difference between entities, the properties of which may in one case be ascribed to the interplay of several molecules within a definite system and in the other case to a peculiar type of organization within one molecule. It may be possible to weave into one large molecule a structure that may be responsible for properties which are quite similar to the properties caused by the interaction of several different molecules in a living system. I think that we may conclude, therefore, that, although it is impossible to decide whether viruses are different from ordinary organisms on the basis of any one of the differences,

the collective picture strongly indicates that there is a difference between viruses and ordinary organisms as we know them.

It is interesting to speculate as to whether or not the fundamental difference is that in the virus proteins we have an example of the vital substance of protoplasm. The virus proteins isolated so far have been found to be nucleo-proteins having unusually high molecular weights. It may be possible that in this chemical combination of nucleic acid and high molecular weight protein we have sufficient organization within a single molecule to endow it with the lifelike properties that characterize it. Such an entity might be regarded as the simplest type of organism, an organism from which all extraneous material has been removed and which has become so highly parasitic that it can reproduce only under very special conditions. Green has already pointed out that an intracellular microbe might be expected to undergo a loss of function due to the assumption of such function by the surrounding protoplasm. Such retrograde evolution he states might progress to the point where only a single molecule remains, and this molecule would be expected to possess unusual properties but would be functionally complete only when immersed in protoplasm. We would, therefore, have an entity possessing all the physical and chemical properties of a molecule and at the same time the potential properties of an organism, without it itself being a functionally complete organism. It is obvious that this description fits the virus proteins. It may be that there is something intermediate between such an entity and ordinary living organisms. Studies on some of the larger viruses such as vaccinia should settle this point. Whatever the outcome of these studies, it seems unlikely that they will alter our conception of the smaller viruses; hence we may proceed with our discussion of the virus proteins.

It is interesting to speculate on the manner in which tobacco mosaic virus protein brings about the production of more of the same kind of molecules when placed in contact with the protoplasm of certain cells. This mechanism is of tremendous importance because it is possible that it or a similar one may be responsible for the production of all the specific protein molecules as well as other molecules within living cells. It may be considered to be the very basis of life. I think we may dismiss at once the mechanism by means of which cells divide and thus reproduce, for we are interested in a more fundamental mechanism, the one by means of which the cell grows until it is in a position for the second mechanism to operate. It seems unlikely to me that the basic mechanism is one in which the virus protein absorbs food, discards waste, grows and at some proper moment divides into two molecules after the manner of cells. A mechanism that I like to consider is one based on the surface forces which Dr. Langmuir has demonstrated so vividly in recent years and some of which he described

on Tuesday. You all know how readily you can induce crystallization of substances by merely introducing a tiny crystal of the material into a saturated solution. The atoms come out of the solution and line up in a fashion that is predetermined by the pattern presented in the form of the introduced crystal. In some of the complex silicates such as $Na_2Fe_4Al_{14}B_6Si_{12}O_{59}$ you may have from five to ten different components present in the solution and yet they all arrange themselves according to the pattern that is presented to them. In some instances, this tendency to assume a definite arrangement is so strong that apparently it may occur without the addition of the pattern or crystal seed. In other instances, the arrangement or crystallization will not occur without the pattern first being present. Well do I remember the time at school when a certain compound was synthesized for the first time in this country. Despite repeated attempts under all kinds of conditions, the material could not be caused to crystallize. However, when a small amount of the material in crystalline form, which had been obtained from abroad, was added, the compound synthesized in this country crystallized quite readily, and since then it has been possible to crystallize the material without knowingly adding seed crystals. We say that the laboratory has become "seeded," that small amounts of such crystals probably occur throughout the laboratory. Here, therefore, we have an example of an arrangement that was dependent upon the presence of a pattern and a demonstration that chemically undetectable amounts of material are probably sufficient to serve as a pattern. The forces responsible for this orientation may appear mysterious, yet they are definite and specific and they are real.

Now, let us consider first what may happen on the introduction of a virus protein molecule into a certain cell, and then consider whether or not we may interpret the growth of protoplasm in terms of this happening. It seems likely that in a living cell there exists a vast array of compounds ranging perhaps from salts and simple amino acids, through intermediate compounds such as carbohydrates and polypeptides, to complex compounds such as proteins. Consider whether the virus protein molecule is able through a characteristic structure and the surface forces that I have described to cause all the component parts to come from this storehouse of materials and to line up in orderly fashion alongside the pattern. If we may assume this degree of orientation, then I think we may assume that, inasmuch as the intact virus protein molecule represents a more stable form, there will be a mutual solvation of forces with the formation of the intact molecule which is then freed from its original pattern and ready to begin its own cycle. I have pictured this happening in a rather naïve manner for the sake of simplification. Actually, the synthesis of proteins probably results from a series of interrelated chemical reactions

that are catalyzed by intracellular enzymes. In this connection it is interesting to consider that the final step to which I just referred may consist of chemical reactions catalyzed by the virus protein itself. It may be regarded as being similar to an ordinary enzymatic reaction except that in this case the intracellular reaction is catalyzed by the same kind of molecules that are introduced. It is obvious that for the successful operation of this mechanism there must be present in the protoplasm all the necessary component parts. If one or more is missing, the virus protein cannot be built up. This serves to explain the specificity of viruses, for a virus would be expected to reproduce only in protoplasm containing the component parts of the virus molecule introduced. There is some evidence that tobacco mosaic virus protein is built from such component parts and not from the large proteins normally built up in such cells, for this virus protein reproduces itself in both Turkish tobacco and phlox plants, and it has been found by sensitive serological methods that the proteins normally existing in these plants are quite different. This is an indication that the virus protein is built up from smaller serologically inactive units that must be common to both plants.

Now, if we may assume this mechanism for the reproduction of the virus proteins, may we not assume a similar mechanism for the production of all the proteins that are synthesized within the cell, and hence for the growth of protoplasm? We know that some virus proteins reproduce quite rapidly and others more slowly, hence there must in the first instance be a tendency for the reaction to proceed rapidly and in the latter instance for it to proceed more slowly. Whether this tendency be real or result from the relative lack of a given component, if it exists, it would, together with the mechanism that has been discussed, be sufficient to explain not only the various factors involved in the reproduction of the virus proteins but also the orderly manner of the growth of protoplasm. There could be explained in this manner the reproduction of virus proteins, their reproduction only in certain living cells, the rapid rate of reproduction in some cases and the slow rate in others, the change or mutation of one strain into one or more other strains, the immunity from other strains that results from infection with one strain and the failure of one virus to immunize against a different one. Furthermore, we see that the possibility of synthesizing virus proteins in the absence of living cells is not denied us, for such synthesis should occur provided the necessary components are provided and the proper conditions are achieved. If we are ever able to synthesize virus proteins in the absence of living cells, then we shall have gone a long way toward the synthesis of protoplasm.

I should, perhaps, remind you at this point that I am speaking of fancy and not of fact. I think it well occasionally to assemble all the facts at our disposal, to use them as a foundation and then to allow

our thoughts and fancy to proceed and lead us where they may into the unknown, disregarding the absence of facts that so far we have been unable to wrest from nature. At worst, we may become imbued with erroneous impressions—and even they have occasionally been beneficial; at best, we may secure ideas that will enable us to establish as facts the very ones that gave rise to the ideas. Whatever may be your attitude with respect to this point, I think that you will agree with me when I say that the elucidation of the manner in which the virus proteins reproduce will serve to give us a clearer picture of the manner in which protoplasm grows. Because certain of the virus proteins are available in large amounts and lend themselves readily to experimentation, I think that we are now in excellent position to pursue with great expectation the problem of the reproduction of the virus proteins and eventually that more interesting problem concerning protoplasmic growth.

MODERN MEDICINE—THE CROSSROADS OF THE SOCIAL AND THE PHYSICAL SCIENCES [1]

By Charles Austin Doan, B. S., M. D., F. A. C. P.

In acknowledging the honor you have done the section on medical sciences in permitting one of its members to serve as your president during the past year, may I say first of all that we interpret your action as a recognition of the emergence of medical practice from an ancient and honorable art into a modern, dynamic science of health. Disease has existed on the earth as long as organic life has been known. The archeologist, the geologist, the anthropologist, the explorer, have all contributed affirmative evidence of this belief. The earliest interpretable record dates back some 4½ million years according to the accepted geological calculation of time, and represents a form of parasitism—fossil snails in the act of feeding on crinoids, a species of sea lily. From that time on, as the fossil remains of the earth's earliest inhabitants unfold the story of life before the advent of man, there appears mute evidence of disease as revealed by skeletal abnormalities—fractures, carious teeth, bone necroses—in the now extinct fishes and reptiles. The tsetse fly, today's deadly carrier of cattle plague and African sleeping sickness, has been identified in fossil formations dating back a million and a half years.

Man's arrival on the scene seems to have been greeted by the same onslaught of disease that met the various forms of plant and animal life which preceded him. The "Java man," placed by anthropologists as the precursor of the human race with an estimated age of 500,000 years, shows pathological exostoses of the femur. The "Piltdown man," with an estimated age of 100,000 years and considered the oldest human skeleton yet discovered, has an acromegalic skull. The "Neanderthal man," spanning 75,000 years of elapsed time, has suggested rickets to some anthropologists.

The history and scientific beginnings of medicine extend back to the ancient Egyptians of the very first civilization of which we have written record, some 30 centuries before the rise of the better known Hippocratic school at Cos in Greece. The Smith Surgical Papyrus and the Ebers Medical Papyrus, ancient hieroglyphic records of the

[1] Presidential address delivered before the Ohio Academy of Science, May 14, 1937. Reprinted by permission from The Ohio Journal of Science, vol. 37, No. 4, July 1937.

diagnosis and treatment of disease as practiced some 3,500 years B. C., carry recognizable descriptions of many diseases prevalent in the modern-day world. The observations of the beloved late Prof. Elliott Smith, who by 1930 had examined the remains of some 30,000 ancient Egyptians and Nubians representing every period of the last 60 centuries, and the microscopic studies by the late Marc Armand Ruffer of carefully restored and sectioned mummified tissues, each independently bear direct testimony to the diversity and similarity of human pathologic processes, then and now.

Thus, from time immemorial man has dreamed and speculated and philosophized about the nature and the significance of life, and has shuddered and shrunk and fled from famine and war and pestilence. This amazing world in each succeeding epoch has presented an ever increasing variety of problems, which have challenged the best minds of each age. At the very extreme of complexity, and the last to be satisfactorily approached for solution on a rational scientific basis have been the problems of human health and disease. The true physician has ever stood at the crossroads, receiving the slowly and painfully accumulated facts from any and every scientific source, and has then appropriated, reinterpreted, and applied them in the alleviation of human misery and suffering. As a result, like the shedding of a chrysalis, the basis for health was transformed at the turn of the century from a speculative, descriptive, cumbersome classification of disease to an exact experimental science for the accumulation of verifiable facts about disease. Today, we are seeing the natural result of this metamorphosis in method and technique, derived from the basic natural sciences, in a transfer of the major emphasis in medicine from empiricism to mechanism—from the "cure" of disease to the "prevention" of disease. One by one superstitions based upon error, or upon incomplete knowledge, are giving way to more exact methods of procedure, until we may envisage the composite, ideal physician of the future as embodying an appreciation and a working knowledge of all of the intricacies of fact deriving from the social as well as from the physical sciences.

If there is any lesson which we of this era should have learned from the past it is the basic necessity for cooperative effort. If the common problems which civilized man faces today are to be solved successfully, the cooperative intelligence of many minds, wherever existing, irrespective of race, color, creed, or narrow sectarian viewpoint, must be focused sharply upon them. Peace—progress—our very existence are seriously threatened through failure to appreciate fully the universality of this fundamental principle—applied economically, socially, and politically, as well as scientifically. Medical leadership in recent years has perhaps recognized this challenge more clearly, and realized its sine qua non for survival more fully, than many in other walks of life.

Epidemic disease is no respecter of geographic and racial boundaries, or of economic, political, and social differences, and medical science has had to look to and embrace the intellects capable of solving its problems wherever they have appeared on the face of the earth. Moreover, medical leaders everywhere cooperate in an international health cordon for the dissemination and application of this knowledge, as it becomes available. With transportation and intercommunication in the world today, such that a yellow-fever-carrying mosquito in an airplane wing on the west coast of Africa this morning, may tomorrow be either in continental Europe or South America, and mayhap the next day on our own eastern seaboard, one cannot evade the reality of the imminence of invasion by disease, even though there be some difference of opinion as to the immediate significance of such feats, with reference to other more obvious forms of invasion.

We may agree, perhaps, then, that one of the most important functions being subserved by medical science in the present day is its exemplification of the necessity for, and its demonstration of the ways and means of organization and administration toward, cooperative effort within the nation and between nations. I need only cite the White House Conference on Child Health and Protection during President Hoover's administration, which resulted in the pooling and critical analysis of our scant information in this basic field and the defining of objectives, which since have been methodically and intelligently and cooperatively pursued; or the activities during the past decade under the Research Committee of the National Tuberculosis Association, which has integrated and correlated the research programs in some 14 universities, 3 research institutes, and 2 large pharmaceutical firms, directed toward the better understanding and control, by treatment and prevention, of this great white plague; or the diversified activities and integrating functions of the National Research Council and the A. A. A. S., of which this Ohio Academy of Science is a worthy satelite, for the cross-fertilization of scientific ideas in the broadest sense; or the nation-wide programs for venereal disease and cancer control which are being inaugurated at the present time in this country after the successful mass application of present medical knowledge to these identical problems of disease in Britain and the Scandinavian countries; or the American, British, and League of Nations cooperating committees on the study and control of chronic arthritis, representing a group of crippling, painful, and economically hazardous diseases, which are increasingly challenging the health and happiness of civilized peoples; or the first international conference on fever therapy held in New York City last month with official representatives from the Ministries of Health of 16 countries; or the International Physiological Congress meeting in Boston 2 years ago, and the International Association of Geographic Pathology meeting in Stockholm this summer

with "anemia" as it affects different people in different parts of the world, the topic for discussion for the entire meeting; or, finally, the International Health Board under the Rockefeller Foundation, which through the years has led in the encouragement of the development and exchange of men and ideas in matters relating to world health problems.

It may not be too late to hope, or too egotistical or remote for scientific groups, such as this Academy represents, to believe that many, if not all, of our present seemingly insurmountable economic and social problems would yield more readily and happily to human ingenuity and intelligence, if our leaders and their respective followers were alike endowed with a larger share of their rightful heritage of normal mental and physical health. To that end all such gatherings as the present one contribute more or less directly, and when and if, and not until, the ideal integration of a genetically sound psyche with an optimum somatic and environmental background has been accomplished, will the essential keystone to the arch of human relationships have been provided. "The promise of things hoped for, the essence of things yet unseen," implied in the present material accomplishments of the human race, are alluring to contemplate but impossible to prophesy fully.

The experience of the past half century, during which the spectacular acquisition and practical utilization of knowledge appertaining to the basic organization and reactions of matter has been paralleled by an equally active exploration of the form, composition, and functions of living cells and organisms, provides an increasing number of instances in which the two approaches have interacted to the mutual advantage of each. Studies of the applicability of X-rays to the problems of medicine were begun within a few months after the announcement of their discovery by the physicist Roentgen. Radium and radioactive substances have likewise been appropriated by physicians as rapidly as isolated and concentrated in needles and bombs for therapeutic purposes. Deuterium had hardly been isolated by Urey and confirmed by Johnson and other chemists until its biological significance was being explored, even before all of its chemical properties were known. The high-frequency, short-wave radio field was no sooner found to be the source of discomfort to men working within its immediate vicinity because of the production of fever and malaise, than Whitney of the General Electric Company recognized its potential therapeutic significance and at once enlisted the aid of physicians and bacteriologists and placed the resources of his laboratories at their disposal in the development of this approach to fever therapy. Kettering of the General Motors Research Laboratories followed promptly, designating himself a technical collaborator with the medical investigators in applying modern engineering methods to developing and adapting new

apparatus for experimentation and therapy. Last week a headline in the New York Times, reporting the meetings of the American Physical Society, read: "Progress is made in 'taming' neutron." The next subheading in capital letters only a little less prominent, read: "Physicists are told of Columbia work bringing nearer a powerful aid for Medicine." The X-ray, the gamma rays of radium, the high-frequency current and now the cyclotron. The physicist, the electrical engineer, and the physician have formed a liaison in which each is mutually dependent upon the other. Just as the biologist has been directing the chemist as to which fractions were biologically "active" or physiologically significant—and therefore most important to analyze and synthesize in terms of human health—so the comparative value of the different physical agents developed in the physical laboratories is being appraised and evaluated by the medical investigator as rapidly as evolved. The artificial induction of therapeutic fever by various physical means was inevitable after von Jauregg observed in his Vienna Sanatarium that general paralysis of the insane frequently improved following an intercurrent febrile infection; and, then, had the courage of his convictions, sufficiently, to induce fever reactions by inoculating selected patients under his care with the malaria plasmodium. Keenness of observation was thus followed by inductive reasoning, the test of therapy was successfully applied, and, finally, the bateriological, cellular, and humoral mechanisms by which improvement is accomplished are just now becoming clear. It is of peculiar interest and significance that the first effective treatment for syphilis of the central nervous system was dependent upon the introduction of another disease, malaria, which through the years, until Ross, McCallum, et al., discovered its cause and control, had been one of man's worst enemies, and still is in some parts of the world. The ingenuity of the physician is exemplified at its best in such an instance, where in discovering how to conquer one disease, he learned enough to make it his servant in conquering still another scourge of mankind. With the demonstration of the thermolability of the *Treponema pallidum* and of the gonococcus at human fever temperatures the importance of fever per se in these diseases has been emphasized and the development of physical means for the induction of fever followed naturally and inevitably.

Another example of shrewd inductive reasoning based upon keen observation by a prepared medical mind occurred during the World War. Baer, an orthopedic surgeon with the American Expeditionary Forces, noted that injured soldiers evacuated some hours after severe injury and with wounds teeming with fly larvae, were less frequently found in profound shock and seemed to have a less stormy convalescence, than men with similar but uninfested wounds. After a decade of pondering this observed fact, during which time children with infected

114728—39——34

and crippling bone lesions returned to him constantly with recurrences and metastatic disseminations, despite the most careful application of modern medical and surgical measures, he developed the courage of his convictions. Soliciting the aid of David Miller and other zoologists with an intimate knowledge of the life cycle of the maggot, methods for the reproduction of fly larvae under sterile precautions were developed. In the beginning, some enzyme or chemically active secretion was hypothesized as the active principle; and now allantoin has been identified by the chemists as the effective substance and is replacing the original less esthetic maggot treatment of Mother Nature and the observant surgeon.

Whipple, while studying the comparative value of different foods in the regeneration of hemoglobin in dogs following hemorrhage, discovered that liver was invariably most effective. Minot and Murphy, knowing of these experiments, then, observed that liver fed in sufficient quantities to human patients with pernicious anemia resulted in a prompt and sustained remission. Chemists promptly fractionated liver, and many other tissues, with the eventual isolation of the active erythrocyte maturation principle in a purified and simplified solution suitable for parenteral administration, thus saving the lives of many sufferers from this disease who would rather have died than eat a pound of liver daily for the remainder of their lives. Only later came the keen analysis of Castle, which firmly established pernicious anemia as a deficiency disease dependent upon the exhaustion of an essential hormone in the stomach, and demonstrated that the erythrocyte maturation factor stored in the liver, normally, is the resultant of the interaction of the gastric hormone known as the "intrinsic factor" with an essential dietary or "extrinsic factor" contained in animal protein.

One of the great modern advances in the science of medicine has been the realization that all disease is not necessarily the result of some external circumstance or bacterial invasion, and that there is a distinction between "optimum" health and "apparent" health, i. e., between good, better, and best. Vitamine and endocrine researches in recent years have done most to exemplify the potential threat to health and well-being of deficiency in these vital elements. The chemist and the physician here combine their resources again in the fundamental problems which underlie the deficiency states. Night blindness, ophthalmia, pyorrhea alveolaris, and urinary calculi suggest vitamin A insufficiency. Polyneuritis follows a vitamin B-1 deficiency, and pellagra with dermatitis, pigmentation of the skin, glossitis, stomatitis, and, at times, mental disturbances may be symptomatic of vitamin B-2 complex deficiency. Easy bruising, oozing of the gums, or unexplained oedema may reflect a vitamin C inadequacy, and rickets and dental caries have largely disappeared where adequate vitamin D is available

in the body economy. A lack of calcium may lead to hyperirritability of the neuro-muscular mechanism, tetany. A deficiency in iron leads to hypochromic anemia, and, if iodine is not available, the thyroid gland suffers. In this connection it is important to remember that interference with absorption or utilization of essential specific principles may be quite as significant in producing symptoms as their absence from the diet.

Also a new principle in disease has been recognized very recently through the increasing knowledge of the interdependence and interaction of vital physiologic functions between widely separated and apparently unrelated organs. If the function of one is impaired the normal function of the other may lead to premature or untimely invalidism or death. As examples, may be cited the removal of the normal thyroid gland to recompensate the damaged heart—or the elimination of the spleen in selected instances where it acts to inhibit or make less effective the production of blood cells by the bone marrow.

One of the most fascinating fields for speculation and further investigation at the present moment lies with the ultramicroscopic viruses. Since the original demonstration of the infectious properties of filter-passing sera from which neither aerobic nor anaerobic bacteria could be cultivated, the question of the ultimate nature of these agents has been warmly debated. Do they represent minute living and propagating protoplasmic bodies or are they more nearly comparable to chemical hormones or enzymes? Within the past few months Stanley, plant pathologist at the Rockefeller Institute, Princeton, has reported the isolation, purification, and chemical crystallization of the agent which produces mosaic disease in the tobacco plant. Thus, the possibility of an entirely new set of biological phenomena related to complex chemical molecules is suggested, and the differential criteria separating animate and inanimate molecular structures are reduced almost to the vanishing point. Many of the workers in this field at the present time, while accepting the nonviable nature of tobacco mosaic virus, still believe that other of the viruses may be the earliest and most primitive forms of living matter. Chemistry and biology must, therefore, again function together as handmaidens to pathology.

The plant and the animal pathologist often serve as pioneers in exploring territories in which diseases common also to man exist. Laidlaw's investigations of distemper in dogs and his development of an immune vaccine and therapeutic serum, have given fresh impetus and direction to the search for an effective control of the common cold in man. And Shope's study of the swine influenza which appeared in 1918, coincident with the world-wide spread of human influenza, identified a common etiology for the two diseases through common immunologic reactions. Shope found, however, that in swine it required both a filterable virus and a bacterium closely similar to, if not identi-

cal with, the Pfeiffer or influenza bacillus to cause the disease, a principle similar to one originally postulated by David Smith for lung abscess.

But the devotees of both the social and the natural sciences are facing still another problem of increasing significance and major importance today. Whereas famine and war and pestilence have acted jointly, and frequently coincidently, in the past in the role of Lord High Executioner for the race, and mediators of the law of the "survival of the fittest," it is no longer the physical so much as the social and economic forces attendant upon the transition from a slow-tempo agrarian to a high-tempo industrial civilization, which are picking out the constitutionally unfit and eliminating the psychobiologically inferior. The American disease, as Emerson, Bateman, and others have designated it, challenges the best effort and skill of the modern physician and social worker. This disease camouflages under numerous and varied symptomatologies, but the common denominator of them all is the highly altered tension under which life is lived today, as contrasted with a few decades ago. The human body is a delicately adjusted, exceedingly complex mechanism with very definite limitations which vary constitutionally from individual to individual. The psyche is more important to its proper functioning than many of the organic processes which have received such careful and detailed study in the past. The central nervous system of man by the very nature of its integrating, governing, and association functions reflects this crowning achievement in organic evolution on the earth today. The material creations of this collective brain, nevertheless, are not being "intelligently" directed and mastered and kept servile to objectives and ends, which would be for the best interests of the race as a whole. Annihilation awaits those who either individually or collectively fail to recognize the "handwriting on the wall." The social and natural sciences must together advance even more clearly and definitely into this domain of modern life and, with increasing factual data upon which to base judgments, make certain that a leadership fully conscious of the lurking dangers as well as the potential possibilities directs our destinies.

Claude Bernard, one of the great physiologists of all time, had rare insight into the dominating motivation of those men of science he designated as the Truth Seekers: "Ardent desire for knowledge, and this knowledge really grasped, and yet always flying before them, becomes at once their sole torment and sole happiness. Those who do not know the torment of the unknown cannot have the joy of discovery, which is certainly the liveliest that the mind of man can ever feel. But, by a whim of Nature, the joy of discovery, so sought and hoped for, vanishes as soon as found. It is but a flash, whose gleam discovers for us fresh horizons toward which our insatiate curiosity repairs with

still more ardor. Thus, even in science itself, the known loses its attraction, while the unknown is always full of charm." Or as Pascal put it: "We are in search never of things but of the search for things."

The section of medical sciences in the Ohio Academy of Science salutes you, the underlying, fundamental sciences from which are synthesized new and more effective and essential answers to these problems of individual and community health. We acknowledge gratefully the past contributions upon which medical progress has been built, and solicit a continuing, ever more intimate, and productive liaison, in the best interests of—let us hope—a rising and not a waning civilization.

HISTORY AND STRATIGRAPHY IN THE VALLEY OF MEXICO[1]

By George C. Vaillant
Associate Curator of Mexican Archeology, American Museum of Natural History

[With 13 plates]

Indian Mexico has a past, but not a history. Thousands of mounds are scattered over the country, and in regions suitable for agriculture the plow constantly produces the shattered vessels and tools of vanished people. The modern Mexicans also show their heritage from the past. Thirty-nine percent of them are pure Indian, and another 53 percent are liberally infused with Indian blood. Even as in Italy, where both the citizens and the land which gives them life bear witness to the background of the Roman Empire, so in Mexico one feels and sees the all-pervading influence of the Indian.

Yet where the Roman past is part of the historical instruction of every schoolboy, the history of Indian Mexico is to most of us a closed book, and even the professional scholar finds that most of its pages are blank. The reasons for the gaps in the historical record are threefold: The Europeanization of Mexico, with the consequent indifference to Indian matters; the conscious destruction of native documents as idolatrous in the days of the evangelization of the country; and the rarity in Mexico of Indian tribes with a knowledge of writing which would enable them to keep historical records.

The history of Mexico, from its Conquest in 1519 to the Revolution of 1910, has emphasized the fortunes of European overlords and their relations to each other and the outside world. The overwhelming Indian preponderance in the population has been by no means balanced by similar representation in the economic and the social world. For 4 centuries, Europe, with all the guile and brute force of its state and with all the spiritual powers of its church, has striven to eradicate from the Indian all traces of his native culture. Since the Revolution of 1910, there has been a conscious effort to transform the Indian population from serfdom into active participation in the social and economic life of the country. With this recognition of the Indian as a potential citizen there has come in Mexico a more general esteem for

[1] Reprinted by permission from The Scientific Monthly, vol. 44, April 1937.

the old Indian civilizations, knowledge of which had been kept alive through the ages by the untiring efforts of a handful of priests and scholars, chiefly Mexican, but including some Americans and Europeans.

These men had interpreted and preserved the few first-hand native records that had survived the wholesale destructions of documents and religious paraphernalia. They had also collected and observed the material traces of native culture dug up by farmers and treasure hunters and had tried to identify the makers of these objects and the builders of these temples by interpretation of the native annals at their disposal. It became evident, as time went on, that there was vastly more material in the ground than could be accounted for by the tribes mentioned in the historical records.

Thus in the beginning of the twentieth century, a subsidiary branch of history began to grow up, field archeology, which had for its goal the study of the Indian material culture, its history and development, and its interpretation in terms of human history. One of the chief aims of this branch of research was to try to establish the relative age of the different monuments and cultures. Fragmentary pottery was of the greatest aid in attaining this end. Forms and decoration changed gradually with the years, and each tribe or locality had its own individual expression. By cutting into ancient refuse heaps, where the material at the bottom was necessarily laid down at an earlier date than at the top, and by carefully studying the differences in shape, texture, and decoration of the fragments of pottery found, it was possible to discern the relative age of several ceramic groups. Later, by finding pottery associated with a building, the relative age of that structure could be determined. Furthermore, in Central America, it is quite common to discover that buildings are successively enlarged by filling in and adding to a previous construction, so that the stratigraphical process can be applied to architecture as well as to ceramics.

While such stratigraphical sequences have been established for various parts of Mexico and Central America, the Valley of Mexico is the first where the archeological record is detailed enough to be compared to the historical and where the two lines of research complement and check each other. Let us examine this relationship, which is one of the primary ends of archeological research.

The documentary evidence from the Valley of Mexico consists of two main types. First there were the records kept by the Aztecs and their neighbors, a few of which escaped the wholesale destructions ordered by the Spaniards. These consisted of a type of picture writing, not unlike a rebus, in which the picture of an object could represent, beside the object itself, the same sound with another meaning or as a syllable in another word. Personages and tribes were

represented in this way, while events were depicted pictorially. The dates of various incidents were also given in terms of a 52-year cycle, but no method of distinguishing one cycle from another was evolved. This system caused the same kind of confusion as if we were to date our history in terms of a century only, so that an event recorded as falling in "65" might mean 1065, 1365, or 1865. The Aztec picture records were undoubtedly supplemented by chants or sagas, which gave detail and color to the simple annals set forth in the manuscripts, and some of the records have notes added at a later date in Spanish or Aztec which describe the native text.

Besides these indigenous documents, there were also histories written by Spanish priests and educated Indians after the Conquest. These authors seem to have had access both to the oral traditions and the pictorial records. In most cases their original sources have disappeared or else survive in copies distorted by European draughtsmanship. These later authors were often bewildered by the native method of dating, as would naturally be the case if one lacked a complete knowledge of the events of Aztec history. Thus, by confusing the various cycles, rulers are sometimes fantastically credited with 160-year reigns. But in the main the native records are fairly complete from 1200 to the Conquest and one or two accounts, written after 1519 but based on native traditions, reach as far back as the seventh century.

The history recorded for the Valley of Mexico begins with mythological tales relating to the foundation of the world and to the presence on earth of gods and giants. Then follow accounts of the Toltecs, in which the supernatural is heavily involved. The lists of their rulers do not always agree, but there is strong evidence that the Toltecs actually existed, and the Toltec era is described as a golden age in Mexican history.

Famine and the incursions of savage tribes, the Chichimecs, brought an end to the Toltec Empire in the twelfth century. One of these entities settled in Azcapotzalco and through intermarriage with the remnant Toltecs picked up enough of the earlier culture to achieve a sedentary life. At the end of the thirteenth century Quinatzin, the fourth of the Chichimec line, moved his court from Tenayuca to Texcoco; but insurrection broke out in his former dominion and thenceforth there was bitter rivalry for the control of the Valley of Mexico between Azcapotzalco and Texcoco. In the second quarter of the fourteenth century two groups of people from the Mixteca came to Texcoco bringing not only writing, but also the cult of the god Tezcatlipoca. A few years later the Tenochca, or Aztecs of Tenochtitlan, the modern Mexico City, along with several other groups, filtered into the valley and became tributary to the Tepanecs of Azcapotzalco.

At the close of the fourteenth century the Tepanec succeeded in overthrowing the Texcocans, but their sway was short-lived. In the second quarter of the fifteenth century, the deposed ruler of Texcoco raised a revolt, and enlisting the services of the Tenochcas or Mexico City Aztecs and the Tacubans, destroyed forever the political power of Azcapotzalco. These three city-states then assumed the leadership of the valley and by a series of conquests enlarged their power to cover great sections of southern and eastern Mexico. Gradually the Aztecs supplanted the Texcocans as the dominant political power in the league, but the cultural and intellectual leadership still remained with Texcoco. At the time of the Conquest the Aztec dominion was at its height, but the disaster in store for it at Spanish hands was but an acceleration of the seething hatred felt by the subject people who allied themselves speedily with the white invaders.

This history, culled from documentary sources, resolves itself into several stages or periods:

(1) The legendary period of the foundation of the world.
(2) The Toltec Empire.
(3) The Chichimec period.
(4) The formation of the Texcocan kingdom.
(5) The rise of the Aztec Empire.

We must now see how this pattern compares with the sequence of cultures, derived by excavation. This latter process has been a long one, lasting over 25 years, and still is not complete. While the Department of Monuments of Mexico and the American Museum of Natural History have been most active, yeoman service has been done by the now-disbanded International School, the Stockholm Museum, and the University of Arizona. Now the point has been reached where a correlation can be made between the tribes of the valley and their material culture.

Traces are found of five main culture levels, differing from each other in the form and decoration of their pottery, in the artistic styles of their stone and clay sculptures, and in their architecture. Through the study of the strata in the rubbish heaps, minor time stages can be distinguished within each culture group.

The earliest traces of man were originally found beneath a lava flow at the south of Mexico, but careful stratigraphical analysis of rubbish heaps in the Guadalupe hills, northeast of Mexico City, where similar material was found, revealed a long history for these finds, which resolved themselves into the handiwork of two peoples. The earlier culture, named Copilco-Zacatenco, after the sites where first found, showed five stages of development, represented in 20-foot accumulations of refuse indicative of a long lapse of time. The general culture level was on a par with that of the more developed of our North American Indian tribes. The later finds, called Cuicuilco-

Ticoman, could be divided into three time stages, derived from refuse heaps that, although deep, could not compare to the earlier deposits. In the Cuicuilco-Ticoman culture there were to be seen evidences of a considerable advance in handiwork, for not only were pottery, figurines and stone tools better made and in greater variety than in the preceding periods, but also the presence of mounds and unquestionable representations of gods indicated the beginnings of a formalized religious system. The wide geographic distribution of this culture shows that these remains were the handiwork of an important and populous tribal group.

The third horizon is marked by the finds made at the great pyramid city of San Juan Teotihuacan, northeast of Mexico City. While the earliest of the five periods tentatively defined shows affiliations with a branch of the Cuicuilco-Ticoman culture, the pottery and figurines present a rapid advance in technique and artistic value. Designs are often derived from ceremonial motives and testify that already that ritualistic preoccupation which so characterizes Central American civilization had taken form. Mighty pyramids and elaborate palaces give evidence of a closely knit social organization able to draft manpower to achieve such ends, while excellent stone sculptures indicate good craftsmen and trade with adjacent cultures. The last phase of this civilization is found at Azcapotzalco, apparently after Teotihuacan had been abandoned. Figurines were made in molds, suggesting a curious use of mass production to satisfy the needs of mass religion, but architectural remains at Azcapotzalco reveal none of the grandiose qualities of Teotihuacan.

These first three culture groups have shown a slow development that reaches a peak in the civilization of Teotihuacan. The artistic forms and styles do not evolve progressively, but rather in jerks, as one tribe seems to have driven out another. The most violent change occurs with the introduction of the fourth culture period. Here, at San Francisco Mazapan, a simple complex of human handiwork is found overlying the Teotihuacan remains. While sporadic pieces, presumably obtained by trade, attest to the presence of relatively high civilizations elsewhere, the bulk of the material reveals little evidence of ritualistic, social, or artistic advancement. By studying the traded vessels, connections are obtained with a series of other peoples, some of high and some of low culture, some inhabiting the Valley of Mexico and others as far away as Yucatan. It is as though with the collapse of the Teotihuacan civilization, a number of other tribes had risen to power and filtered into the countryside.

The last culture stage constitutes the articles of household and ceremonial use, the sculptures, and the architecture found in places known to have been occupied by the Aztecs. One very characteristic ware

may be divided into six periods, while other local forms and decorations reflect the presence of city-states mentioned in the chronicles.

The six Aztec pottery periods may also be grouped into larger units. The first period has been found in quantity at only one site in the valley, Culhuacan, and stylistically these ceramics show affiliations with Cholula and the Mixteca, and, by trade pieces, with Mazapan. The second and third periods are closely united, and only minor differences in their coarse style of draughtsmanship distinguish them. The fourth and fifth periods produced highly conventionalized designs that are very similar, but many highly decorated polychrome wares attest to a wide trade. The last period styles evolve from the preceding and a new element of naturalistic decoration also appears.

Here, then, is the logical starting point for a correlation between the archeology of the valley and its documentary history. If the six ceramic periods could be tied in with the annals of the Aztec, then there would be a fairly secure basis for testing the vaguer portions of the valley's past. To this end a curious custom of the Aztec gave us a very good lead.

The Aztecs at the close of each of their 52-year cycles broke all their household utensils and put out their fires. Then they refurnished their houses and made new equipment. Presumably the temples and sacred buildings underwent a similar renovation. After midnight on the last day, a new fire was kindled on a hill outside of Mexico, and runners with torches distributed this flame to all the hearths in the valley, while every one rejoiced that life was to continue for another 52-year span. The native chroniclers record this practice punctiliously, for the Mexican calendar system was a sacred almanac for governing men's lives and served only secondarily as a means of recording time.

Reflections of this ceremony have been found in excavations around Mexico City, where broken pottery and idols were found in too great quantity to have been the result of accidents. Ancient temples, in which the successive additions give the nested effect of a Russian doll, also suggest a further application of this practice.

One of these cyclical dumps yielding pottery of the fifth Aztec style we uncovered in the spring of 1936 at the power plant of Nonoalco in the heart of Mexico City. A normal refuse heap of the sixth and latest style lay above the ceremonial deposit. Since this latest type of Aztec pottery occasionally shows such traces of Spanish influence as glazed surfaces and European designs, it must have been in vogue at the time of the Spanish penetration of Mexico subsequent to 1519. Therefore we had good basis for assuming that the lower layer of the fifth period represented the destruction in connection with the last New Fire Ceremony before the conquest, which was celebrated in 1507. Moreover, at Chiconauhtla, a frontier town of the Texcocan dominion,

we found another ceremonial dump of this same fifth Aztec style under circumstances which proved it to have been made at the end of the occupation there.

To strengthen our hypothesis we found two dumps of the fourth Aztec ceramic period, one at Chiconauhtla and another in Texcoco itself, an occurrence which would suggest the celebration of the New Fire Ceremony 52 years previous, or in the year 1455 (1507–52=1455). In one of the earlier buildings at Chiconauhtla, we came across another such dump composed of pottery of the third Aztec period, which, if our hypothesis was correct, would represent the cyclical destruction of 1403.

The second Aztec pottery stage was obtained from a low stratum of a normal refuse mound at Chiconauhtla, so that while we have no definite evidence that this earlier stage should span another 52-year period, we have some right to assume it was made between 1299 and 1351. Furthermore, the first Aztec period, as we have said, is found in quantity at only one site in the valley, Culhuacan, and may well be contemporaneous with the Mazapan culture described above as representing the fourth epoch in the development of civilization in the valley.

According to our reckoning, then, the Period 6 style, from 1507 to the Conquest, represents the last days of the Aztec Empire. Pottery of Period 5, which was made between 1455 and 1507, is widely distributed as befits the domination of the Aztec League. The method of decoration in vogue in Period 4, 1403–1455, is strongly represented at the palace of Nezualcoyotl, the great Texcocan ruler, and at Texcoco itself. At this time Texcoco rather than Tenochtitlan led in sumptuousness and splendor. The trade wares suggest tribute from the conquests of that era and the clay idols reproduce the wide variety of gods in the Mexican pantheon.

Pottery from Period 3, 1351 (?)–1403, is scantily represented at Tenochtitlan, which in this period was a weak tributary to Culhuacani and the Tepaneca of Azcapotzalco, but this style, like that of Period 2, 1299 (?)–1351 (?), is found in the other valley centers. During the fourteenth century as we have seen, the Tepanecs, Texcocans, and Culhuas held the leadership of the Valley of Mexico, and the pottery attributable to this period is most commonly found in the towns under their dominion.

Confirmatory evidence of the reflection of time in ceremonial practice is yielded by the pyramid of Tenayuca, where seven buildings are found superimposed. The last reconstruction presumably marks the ceremonies of 1507, the next two in the same style, those of 1455 and 1403. The architecture of the fourth (1351) is transitional to two more primitive pyramids possibly representing the ceremonies of 1299 and 1247 which corresponds very well to the early thirteenth century date given to the founding of the Chicimec kingdom in Azca-

potzalco. The break from the primitive to the regulation Aztec style of architecture accords well with the historical data, which describe Quinatzin's becoming civilized and moving to Texcoco in 1298 and the arrival of Mixtecs and other tribes in 1328. A resemblance, too close to be entirely coincidence, exists between the tradition of the Mixtecs having brought knowledge of writing in 1328 and the Period 2 and 3 style of decoration which seems based more upon the fluid principle of writing than the previous labored method of painting designs in geometric fashion.

We have traced our way to the last half of the thirteenth century. Our records have become very hazy, and we now meet the Mazapan culture, the fourth level in the valley. The chronicles tell of the incursions of the Chichimecs who brought an end to the Teotihuacan culture some time in the twelfth century. We can rely no longer on ceremonial dumps, but we can achieve a relative dating in another way. Two trade wares are found in the Mazapan culture, Plumbate, a natural glazed pottery perhaps made in Salvador, and Fine Orange, which is common on the Isla de Sacrificios in Vera Cruz. Both these wares are frequently found in Chichen Itza in refuse of the Mexican period, which began about 1200 A. D. and lasted until 1458. That the Mazapan culture flowered in the thirteenth century seems extremely probable both because of its stratigraphical position below the Aztec-Texcocan material remains and above those of Teotihuacan, and because of the trade pottery which ties in with thirteenth century refuse heaps at Chichen Itza in Yucatan. The makers must then be some branch of the Chichimec immigrants, who, arriving in Mexico during this period, seem to have assumed distinctive tribal names even as, in adopting a sedentary life, they occupied fixed places of residence.

Following our method of elimination there seems no reasonable doubt that the Toltecs were the makers of the Teotihuacan civilization, a thesis which is supported by a great deal of legendary evidence. The long span of the 700–1200 A. D. dates assigned by some to the Toltec Empire agrees well with the traditional evidence and the retarded cultural development one would expect of people who could not borrow but had to invent each material and cultural innovation. Furthermore, this hypothetical dating is roughly substantiated by the discovery of the Swedish archeologist, Linné, who found, in a Toltec building on the outskirts of Teotihuacan, Peten Maya trade pottery like that associated with the dated Maya monuments (*circa* 433–889).

While the historical position of the Valley of Mexico Toltecs seems to be fairly well established by the correlation of archeological and historical data, there is still confusion attendant to the cultural identification of people called by the same name in other districts of

Mexico. Further research should clear up the identity of these tribes, as either colonists driven out of the valley or outlying branches of the same group who retained their tribal organization although modifying their culture, or perhaps people completely different culturally and tribally who were given this name as a generic distinction, even as the discoverers of America called its inhabitants Indians.

With this final identification, connection between traditions and archeology ceases, so that we cannot identify the makers of the Cuicuilco-Ticoman and Copilco-Zacatenco cultures, often grouped under the term "Archaic." True, the mythology records giants as inhabiting the earth before the advent of the Toltecs, but the skeletons found in graves of these periods give no evidence of extraordinary size. It would be tempting to align with mythical destructions of the world the rise in lake level which affected the Zacatenco culture or the lava flow from the Pedregal which surrounded the ruins of the Cuicuilco pyramid. As these successive destructions were by jaguars, wind, fire, and water, the order is wrong for such an interpretation of the geological disturbances affecting the early cultures, but it is possible that a vague folk memory of such events may have been incorporated in the myths.

The dating of these early cultures is impossible in an absolute sense, but, relatively, some estimate may be made. The geologists all agree that the lava flow is recent, but their computations of 2,000 to 8,000 years are meant to be taken in the geological sense of extreme youth instead of the historical sense of great age. There is some evidence that the Ticoman-Cuicuilco culture is partially contemporaneous with Teotihuacan. It is also possible to compare the accumulations of rubbish at Zacatenco and Ticoman with those of a site in New Mexico, Pecos, the occupation of which is accurately known in years by means of the tree ring method of dating. Dividing the number of years by the greatest depth of continuously deposited debris at Pecos, one gets a ratio of 78 years to the meter. Applying this computation to the deepest refuse heap at Ticoman, one finds 286 years of accumulation, and to the thickest middens of the Copilco-Zacatenco culture, 787 years. Perhaps a thousand years is excessive, so that computing on the basis of the deepest bed which shows continuous occupation by both cultures, one arrives at nearly 600 years for the total length of habitation.

Rough and inaccurate as these computations are they indicate that the Valley of Mexico was inhabited for a long time before even the dimmest historical records, and that the earliest remains so far recovered were made in the first centuries before the Christian Era. However, these early people were by no means primitive. Indeed they were on a par already with our modern Pueblo, and there are many stages of culture to be discovered and analyzed before we can say we have traces of the earliest man in Central America.

This article has endeavored to sketch one phase of historical research on the past of Mexico. A major problem has been to bridge the gap between the peoples who are identified by Spanish and Indian documentary records and those who are known to us only through the ruins of their buildings and the broken elements of their material culture which have survived. While at times it must seem as though the archeologists labor to make bricks without straw, yet the results of the Valley of Mexico research prove that it is possible to formulate a history with the meager data provided. In Yucatan, Guatemala, and Oaxaca, similar methods have sketched the main outlines of historical development. Even if the history thus obtained discloses little or nothing of the life of the individual, it does throw abundant light on the steps by which man achieves his artistic development and economic progress. The lesson is constantly driven home that greater than man is the sum total of his achievements.

TYPES OF STRATIGRAPHICAL EXCAVATION IN THE VALLEY OF MEXICO.

Top: *Left:* Deep pit at El Arbolillo, Federal District, Mexico. The earliest discovered figurine types from the Valley of Mexico were discovered at the base of this trench. *Right:* Cleaning out a canal in the Nonoalco District of Mexico City. This shallow ditch was filled with vessels discarded in the cyclical destruction of 1507.

Middle: Excavation in the Nonoalco District.

Bottom: *Left:* Peeling layers of refuse at Zacatenco, D. F. This was the source of the first stratigraphical series defined by the American Museum of Natural History. *Right:* Dissecting an Aztec residential structure at Chiconauhtla, State of Mexico.

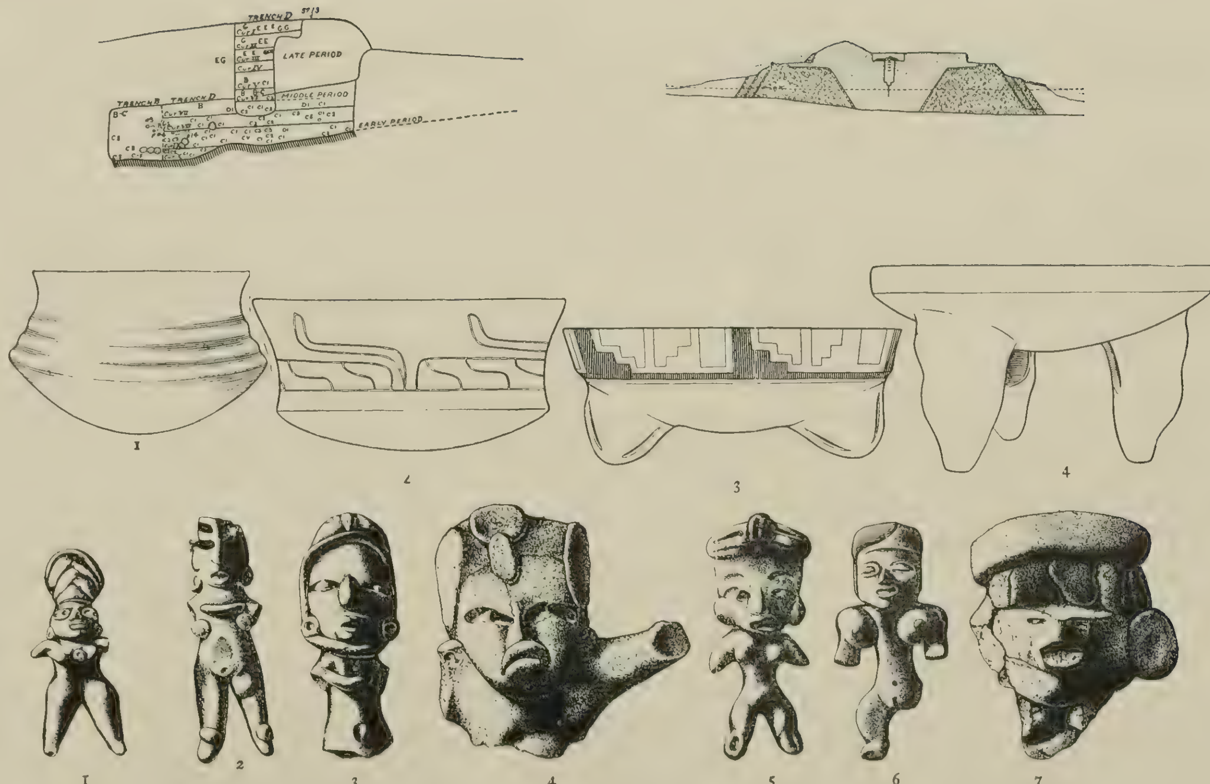


CHART SHOWING NATURE OF ARCHEOLOGICAL MATERIAL FROM THE ARCHAIC CULTURES.

Top: *Left:* Section through refuse heap. *Right:* Cross section of mound at Cuicuilco.
Middle: 1–2, pottery vessels from the Copilco-Zacatenco horizon; 3–4, pottery vessels from the Cuicuilco-Ticoman horizon.
Bottom: 1–4, figurines from successive stages of the Copilco-Zacatenco culture; 5–6, figurines from successive stages of the Cuicuilco-Ticoman culture; 7, head of archaic Teotihuacan type, derives stylistically from fig. 5.

POTTERY VESSELS FROM EARLIEST COPILCO-ZACATENCO HORIZON.

FIGURINES (TYPE C3A) FROM EARLIEST COPILCO-ZACATENCO CULTURE LAYER.

SPECIMENS FROM THE ARCHAIC CULTURES.

Top: *Left:* Mother and child from Cuernavaca, Morelos. *Center:* Pyramid of Cuicuilco, D. F., note the lava encroaching on the mound. *Right:* Figurine, Cuernavaca, Morelos.
Middle: *Left:* Large hollow figurine, Cuernavaca, Morelos. *Right:* Head, Zacatenco, D. F.
Bottom: Pottery vessels of the Cuicuilco-Ticoman culture, Ticoman, D. F.

CHART SHOWING NATURE OF MATERIAL FROM THE TOLTEC CULTURE.

First row: Fresco from Teotihuacan, showing people involved in a ritualistic ceremony.
Second row: Reconstruction of the Pyramid of the Sun at Teotihuacan, after Gamio.
Third row: Pottery vessels, Toltec culture.
Fourth row: Successive stages of figurine manufacture in the Toltec culture. The last two are mold-made.

PYRAMID OF THE SUN AT TEOTIHUACAN, STATE OF MEXICO.

1 2 3 4 5 6 7

TOLTEC FIGURINES.

Nos. 1–5, Teotihuacan II (early Toltec) type. Nos. 6–7, Teotihuacan V (late Toltec) type. Note in nos. 3–4 grotesque features indicative of symbolism defining various deities.

CHART SHOWING ARCHEOLOGICAL MATERIAL FROM THE CHICHIMEC CULTURES.

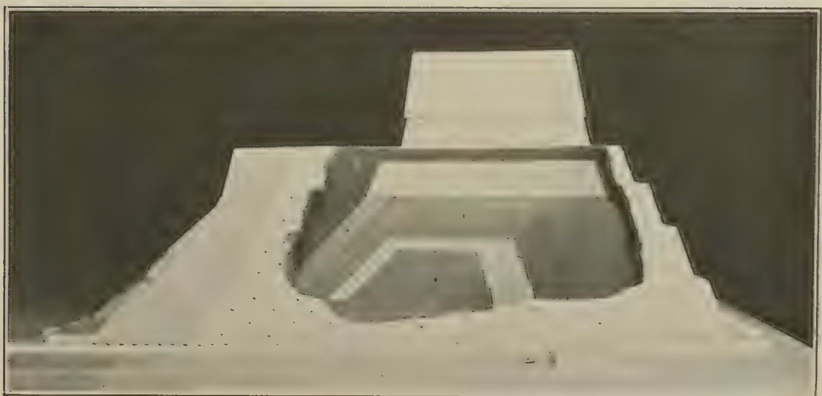
Top row: Historical picture writings relating to period. *Left:* Chichimec hunter. *Center:* Aztecs setting forth on their wanderings. *Right:* Eight tribes who settled in and around the Valley of Mexico.
Second row: Successive stages in the construction of the Temple of Tenayuca which epitomizes the architecture of the Chichimec and Aztec periods.
Third row: Pottery styles of Mazapan, Coyotlatelco, and Aztec I type which may eventually be correlated with some of the tribes shown in top row, right.
Fourth row: Figurines of Coyotlatelco type.
Fifth row: Figurines of Mazapan type.

1. Life-size pottery effigy from Coatlinchan, State of Mexico. Stylistically this figure seems to belong to the Mazapan culture.

2. Upper: Pottery effigy vase from Mazapan, State of Mexico. Lower: Two bowls of plumbate ware from Mazapan. This is an important ware for cross dating culture periods.

1. TEMPLE OF CHOLULA, PUEBLA.

Beneath this large adobe platform is a complex of buildings of the Toltec period.



2. MODEL OF THE TEMPLE AT TENAYUCA, D. F.

Showing successive renovations made in connection with the renovation ceremonies at the beginning of calendar cycles. The six buildings shown might correspond to structures made in 1507, 1455, 1403, 1351, 1299, 1247.

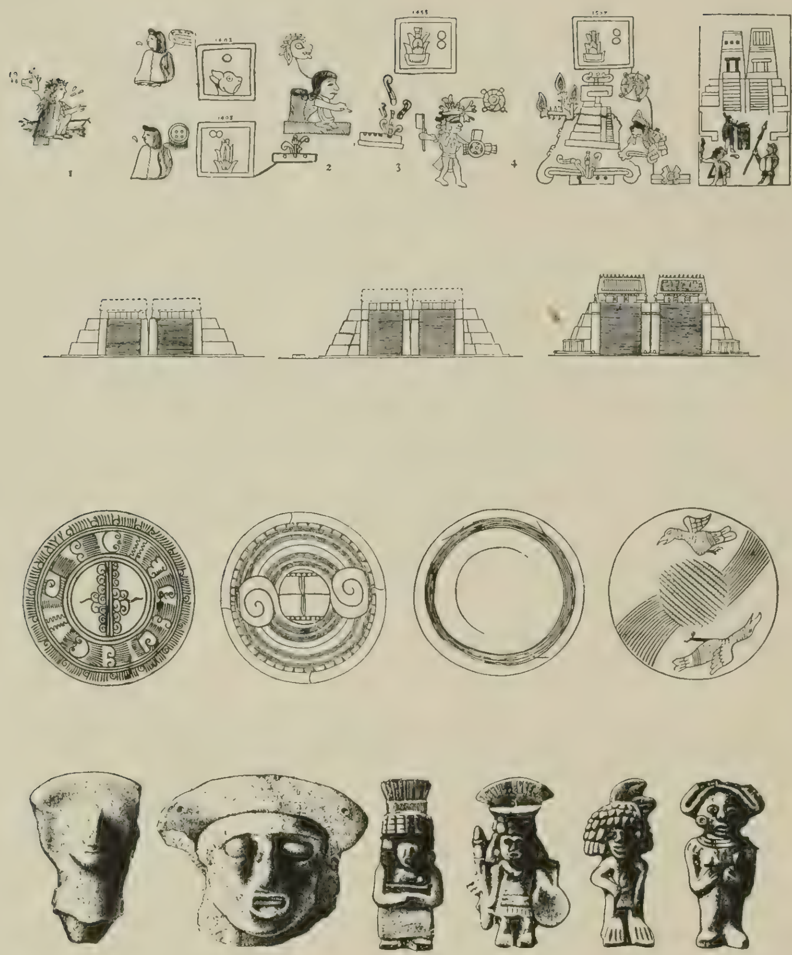


CHART SHOWING ARCHEOLOGICAL MATERIAL FROM THE AZTEC CULTURE.

First row: Scenes from historical picture manuscripts. 1, Arrival of nations with the knowledge of writing in 1325; 2, New Fire Ceremony of 1403: 3, New Fire Ceremony of 1455; 4, New Fire Ceremony of 1507; 5, the taking of Tenochtitlan (Mexico City) in 1519.
Second row: Successive stages in the architecture of the Temple at Tenayuca, corresponding perhaps to the renovations of 1403, 1455, and 1507.
Third row: *First three:* Aztec pottery types (II, IIIa, IIIb) found in the cyclical dumps for 1403, 1455, and 1507. *Fourth:* Pottery type (IV) made from 1507 up to the Conquest.
Fourth row: *First two:* Aztec figurines made prior to 1403. *Last four:* Aztec figurines made between 1403 and the Conquest.

AZTEC POTTERY TYPES.

Top Trichrome vessels found in a 1403 cyclical dump at Chiconauhtla.
Middle: *Right:* Trade bowl found in 1507 dump at Chiconauhtla. *Left:* Local trichrome bowl found in the 1507 dump at Chiconauhtla.
Bottom: *Left:* Orange-on-red bowl with black outline from Nonoalco. *Right:* Black-on-orange dishes from Nonoalco.

THE FOLSOM PROBLEM IN AMERICAN ARCHEOLOGY [1]

By Frank H. H. Roberts, Jr.
Archeologist, Bureau of American Ethnology

[With 15 plates]

The so-called Folsom problem has assumed an important place in American archeology during the last decade. It is outstanding in popular interest, and in scientific circles it is regarded as significant. This is due to the fact that it is closely coupled to the question of early man in the New World. At several places in New Mexico and Colorado implements have been found in association with bones of extinct animals and in deposits suggestive of geologic antiquity. These discoveries help push the date of occupation farther back into the past and have encouraged renewed consideration of the length of time that man has been in America. The more important sites where such finds have been made are those near Folsom, between Clovis and Portales, and in the Guadalupe Mountains in New Mexico; and at the Lindenmeier ranch and Dent in Colorado (fig. 1).

The first in the series—that which gave its name to archeological remains of the type—is on a small intermittent tributary of the Cimarron River, in a little valley named Dead Horse Gulch, several miles west of Folsom, Union County, N. Mex. It lies below the eastern rim of Johnson Mesa and was discovered in the summer of 1925 by local residents. Fred J. Howarth and Carl Schwachheim of Raton, N. Mex., reported the find to J. D. Figgins, then director of the Colorado Museum of Natural History at Denver, now director of the Isaac W. Bernheim Foundation, Louisville, Ky. Bones sent to the museum showed that the remains were those of an extinct species of bison and of a large deerlike member of the Cervidae. Prospects for fossil material were so promising that the Colorado museum sent a party to the site in the summer of 1926. Bearing in mind an occurrence 2 years previous when another group from the museum was digging near Colorado, Tex., and uncovered two chipped-stone objects in

[1] Reprinted, by permission, with some revision, the addition of new information, illustrations, and references, from Early Man, as depicted by leading authorities at the International Symposium, the Academy of Natural Sciences, Philadelphia, March 1937. J. B. Lippincott Co., 1937.

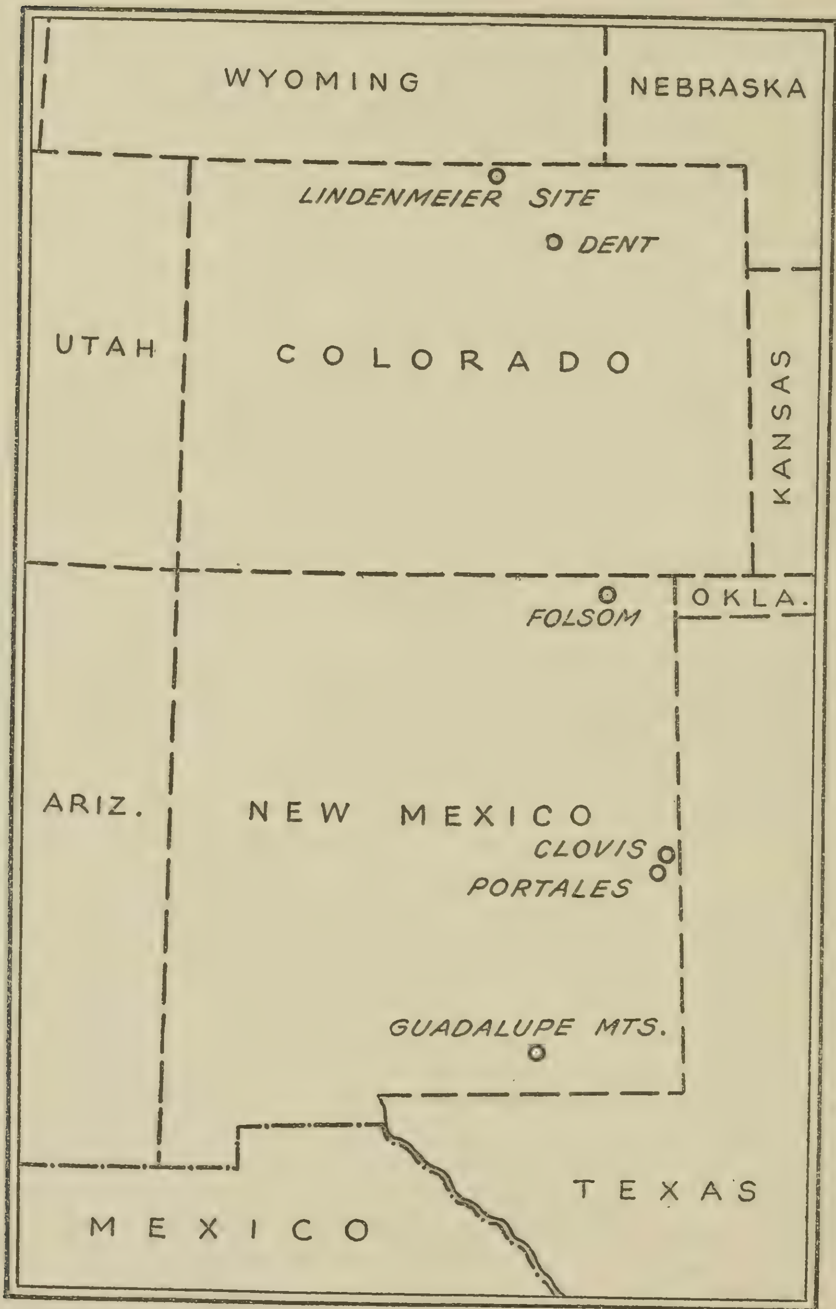


FIGURE 1.—Locations of principal Folsom sites.

association with an extinct bison, but failed to preserve their evidence in acceptable form, Mr. Figgins gave explicit instructions for the workmen to watch carefully for such artifacts at the Folsom pit. Parts of two finely chipped projectile points were recovered from the loose dirt during the excavations (pl. 1, fig. 1, *a*, *b*, *c*). Near the place where one of them was picked up, a small triangular piece of stone was found embedded in the clay surrounding an animal bone. This fragment was left in the block of earth and sent to the laboratory at Denver. When the dirt was carefully cleaned away from the stone it was noted that it was of the same material as one of the points. Close examination showed that it was actually a part of the point as the two pieces fitted together (pl. 1, fig. 2). This indicated a definite association between man-made objects and an extinct bison. Mr. Figgins was greatly impressed by the find and reported it to a number of archeologists and general anthropologists. The information was skeptically received in most quarters, and in several instances there was a definitely hostile attitude toward suggestions that the occurrence might be of importance and worthy of further investigation.

The Colorado Museum again sent a party to Folsom in the summer of 1927 and had the good fortune to find additional points. One of these was noted before it was completely uncovered, and work was stopped. Telegrams were sent to various institutions inviting them to send representatives to view the point in situ. Dr. Barnum Brown, of the American Museum of Natural History, New York, and the writer responded. Arriving at the quarry (pl. 2, fig. 1), he found Director Figgins, several members of the Colorado Museum board, and Dr. Brown. The latter had just uncovered the point which became the pattern and furnished the name for the type. There was no question but that here was important evidence. The point was still embedded in the matrix between two bison ribs (pl. 2, fig. 2). In fact, it has never been removed from the block, which is now on exhibit in the Colorado Museum of Natural History at Denver. The writer returned to Raton and telegraphed Dr. A. V. Kidder, then associated with Phillips Academy, Andover, now with the Carnegie Institution of Washington, and urged that he also visit the site. Dr. Kidder, who was engaged in excavations at Pecos, N. Mex., arrived 2 days later. After the whole situation had been studied carefully, it was agreed that the association could not be questioned nor explained away by any of the customary arguments against the authenticity of such an occurrence. That winter Dr. Brown, Dr. Kidder, and the writer reported on the finds at the annual meeting of the American Anthropological Association at Andover, Mass. In spite of the convincing nature of the evidence, most of the anthropologists continued to doubt the validity of the discovery.

The American Museum of Natural History and the Colorado Museum cooperated at the site in 1928. Dr. Barnum Brown headed the expedition, taking charge of the actual excavations, and several graduate students in anthropology under the supervision of Dr. Clark Wissler, head curator of anthropology at the American Museum, assisted by making a survey of the surrounding area in search of caves, rock shelters, or camp sites where the makers of the points might have lived. The survey had negative results, but the diggers were more fortunate. Additional bison skeletons were found with accompanying points, and numerous specialists—archeologists, paleontologists, and geologists—went to check the evidence. Consensus was that the finds were a reliable indication that man was present in the Southwest at an earlier period than formerly supposed and that they constituted one of the most important contributions yet made to American archeology. Most of the critics of previous years became enthusiastic converts and endorsed the Folsom materials. While the finds and their establishment as authentic were significant, of even greater consequence was the fact that Folsom paved the way to more considerate and unbiased studies of other discoveries indicative of an earlier New World occupancy and made it possible for those interested in that subject to continue their investigations without inviting the stigma of charlatanry. An ever increasing tendency to condemn arbitrarily any occurrence even slightly suggestive of antiquity gave way to the more reasonable attitude of letting the facts decide the case.

The points associated with the bison bones differed from the ordinary types scattered over that portion of the Southwest. They are leaf-shaped blades characterized by a longitudinal fluting on each face. One of the examples found in 1926 (pl. 1, fig. 1, *a*, *b*), at first glance appears to have a channel on one side only, but that is due to the fact that the basal portion is missing and that the break occurred just above the end of the groove. This feature is apparent when the photograph (pl. 1, fig. 1, *b*), is examined closely. In addition to the channels, the points have a secondary chipping along the edges that bespeaks a highly developed stone-flaking technique. Owing to the proximity of the site to the town of Folsom, these points were generally referred to as Folsom points, and later were definitely so named by Mr. Figgins. Because the site represented the scene of a kill rather than a camp, other artifacts were scarce, a portion of a nondescript flake knife and a generalized type of scraper being the only additional forms; hence, for a time the point was the only implement recognized as Folsom.

The layer of bones and implements at Folsom were in a deposit of dark clay containing lenses of gravel and small concretions of lime. This alluvial stratum probably represents an old bog or water hole that was the principal reason for the presence of the animals. At the

conclusion of his work Dr. Brown emphasized the fact that the sediments overlying the bone bed were highly restratified earth of a nature indicating great antiquity. He concluded that they belonged to the close of the Pleistocene and placed the age of the remains at the end of that period. Some of the experts support this opinion. Others believe that the site should be considered Early Recent rather than Late Pleistocene, and there the matter rests today.[2]

The second important New Mexican area contains several sites. It lies approximately 160 miles southeast of Folsom, between Clovis and Portales, not far from the Texas-New Mexico boundary (fig. 1). The sites were reported to Dr. Edgar B. Howard of Philadelphia in the summer of 1932 by A. W. Anderson and George Roberts, of Clovis. Dr. Howard visited the area at that time and returned again in November of the same year, when a road-construction company, digging for gravel, exposed a layer of bluish clay containing quantities of animal bones and indications of human occupation. As a result of that inspection he planned a series of investigations for the summer of 1933. This began as a joint undertaking of the Academy of Natural Sciences and the University of Pennsylvania Museum. Later in the season Dr. John C. Merriam, president of the Carnegie Institution of Washington, visited the excavations and became so enthused over the prospects that he arranged for the California Institute of Technology to send a party, under Dr. Chester Stock, to cooperate in the work. Dr. Howard returned in the summer of 1934 in company with Dr. Ernst Antevs who studied the physiography of the region in an endeavor to date the sites. Dr. Howard again led a party to the Clovis sector in the summer of 1936. This was a joint project of the Academy of Natural Sciences and the Carnegie Institution of Washington. The work was continued in 1937 under the auspices of the University of Pennsylvania Museum and the Academy of Natural Sciences, with Dr. Howard acting in a supervisory capacity and John L. Cotter in direct charge of the excavations.

The Clovis-Portales area is part of the Staked Plains, the old Llano Estacado of the Spanish explorers. In this district the flatness of the terrain is broken only by sand dunes rising along the edges of shallow depressions. These dry basins occur in a series that extends in a general east-southeasterly direction about midway between Clovis and Portales. Evidence points to a former period of heavy precipitation. At that time the basins were more or less permanently filled with water. Subsequent desiccation reduced them to mere water holes. They eventually dried up entirely and were filled with drift sand. Recent wind and water action have left them in varying stages of erosion. The sand has been whipped up into dunes along

[2] For more detailed information on the Folsom site, see Brown, 1929; Bryan, 1937; Cook, 1927; Figgins, 1927; Roberts, 1935.

the northeastern borders of many of them, exposing a hard bluish-gray deposit. These constitute what are known locally as "blow-outs" (pl. 3, figs. 1 and 2). In some the bluish layer has been cut down to a harder, underlying stratum of caliche, leaving shelves or benches around the edges of the basins and "erosion islands" scattered through the middle. Excavations in these shelves and islands yield animal bones, stone artifacts, some bone tools, charcoal, and ashes. Many of the bones show the effects of fire, and a large number appear to have been cut and split for the marrow. In numerous cases there is a definite association between the bones and man-made objects. The bones represent an extinct species of bison and the mammoth (pl. 4, fig. 1). Hence, there is little question but that in this region man was contemporary with both animals. Camel and horse bones are present in lower levels antedating the human period of occupancy.

Implements found there comprise projectile points, various kinds of scrapers, rough-flake knives, knives, blades, gravers, bone tools of unidentified function and two sharpened bones that may have served as spear points. Some of the stone projectile points are significant because they are comparable to the fluted examples from the original Folsom quarry. Others do not have as pronounced channels, and some do not have the feature at all. The latter correspond to a much disputed form called the Yuma. The presence of the fluted forms is an indication of some cultural relationship between the makers of these implements and those from the Folsom pit. The meaning of the so-called Yuma specimens is not clear. They may belong to the Folsom implement complex, but it is possible that they represent trade objects or an influence from another complex. This is still to be determined. One theoretical study based on typology, without any actual stratigraphic evidence, derives the Folsom type from the Yuma. The validity of this hypothesis is made questionable, however, by the fact that in some localities Folsom materials are found without any associated Yuma points and in others the Yumas occur and the Folsoms are absent. Furthermore, numerous channel flakes and unfinished Folsom points show that the chipping technique was not the same as that employed on the Yuma specimens (pl. 4, fig. 2). The specimens from the Clovis-Portales sites demonstrate that the fluted points belong to a definite complex and that they are only one of a series of different types of implements rather than the major item in the material culture of a hunting people as the evidence from the original Folsom pit would tend to indicate.

General interpretation of the geologic evidence is that the blue-gray stratum in the Clovis-Portales region was a lake deposit, probably laid down when temperatures were lower and there was much more precipitation. These conditions have led Dr. Antevs to conclude that the time represented corresponds to the end of the Pleistocene period,

his pluvial stage, dating back 12,000 to 13,000 years in this particular district. A more recent study suggests that the horizon from which the artifacts come is the flood-plain bottom land of a Pleistocene river rather than a lake deposit and that the age is much greater than that indicated by Antevs.[3]

At Burnet cave in the Guadalupe Mountains, southeastern New Mexico, Dr. Howard found a fluted point in association with bones from an extinct bison and an extinct muskox-like bovid. The point differs in some respects from the typical Folsom form, despite the channels, and falls in the category of Folsom-like or Folsomoid, terms used by some investigators to indicate a variation in the fluted forms. The point probably belongs to the basic Folsom type, however, and for that reason has a bearing on the general problem. The association of point and bones in itself is indicative of some antiquity, but there is further significance in the fact that it occurred in a stratum underlying Basket Maker material. The Basket Makers represent the oldest definitely established horizon in the culture-pattern sequence of the Pueblo area in the Southwest and date back some 2,000 years. There is some question as to whether or not the peripheral Basket Maker material found in the Guadalupes and the Big Bend region farther to the southeast is actually as old as that from the main Basket Maker center, but the point and the bones unquestionably are of considerable age as they were in a hearth 4 feet below the bottom of the Basket Maker level.[4]

The Lindenmeier site is 28 miles north of Fort Collins, Colo., 1½ miles south of the Wyoming line (pl. 5, figs. 1 and 2). It was discovered in 1924 by A. L. Coffin, his father Judge C. C. Coffin, and C. K. Collins, all residents of Fort Collins. During the decade 1924 to 1934 the judge, his son, and a brother of the judge, Maj. Roy G. Coffin, of Colorado State College, visited it intermittently and collected specimens. From the beginning of their finds they recognized that the points were different from the ordinary arrowheads so abundant in the region but were not aware of their true significance until 1931 when they learned that they were Folsom type. Most of their material was gathered from the surface. A few implements and some bone scraps were scratched out of the soil, but there was no attempt at extensive digging. The site was brought to the attention of the Bureau of American Ethnology, Smithsonian Institution, by Major Coffin in the summer of 1934. As a result of a series of letters from the Major, the writer went to Fort Collins in September. The owner of the land, William Lindenmeier, Jr., gave permission for a series of investigations, and preliminary prospecting was started. This first

[3] For detailed studies of the Clovis-Portales sites, see Antevs, 1935a; Bryan, F., 1938; Cotter, 1937, 1938; Howard, 1935; Stock and Bode, 1936.

[4] Howard, 1935a, pp. 62–79.

work was continued through October and into November. Most of the digging was confined to a deep pit in an arroyo bank, where there was an exposed layer containing bones and artifacts (pl. 6, fig. 1), although some excavations were made at other portions of the site in an effort to determine its extent.

In 1935 two large trenches were dug across the portion of the site lying south of the deep pit in the ravine (pl. 6, fig. 2). This was done to reveal a complete cross-section of the deposits overlying the specimen-bearing stratum and to determine the source of the objects found in the deep pit (pl. 7, figs. 1 and 2). Trenches were also dug through a portion of the area near the location of the original Coffin finds. A bone pile comprising remains from nine individual bison, *Bison taylori*, the same species found at Folsom, was uncovered (pl. 8, fig. 1). Further work carried on at this location in 1936 revealed the remains of a feast or barbecue. The carcasses of the animals, those found the previous year and others included in the new material, had been dismembered and cooked at the scene of the kill. Many bones were charred and several projectile points recovered from the debris exhibit the effects of fire. In addition, numerous implements of various kinds were associated with the bones. Any lingering doubts concerning the contemporaneity of the makers of Folsom points and the extinct bison were dispelled when the tip end of a point was found in situ in the channel for the spinal cord in one of a series of articulated vertebrae (pl. 8, fig. 2). Further interest was added by the fact that several foot bones from a camel, probably *Camelops*, were in the assemblage. Excavations made near the previous year's trenches yielded ample evidence of human occupation. There were traces of surface fires, quantities of debris left by the makers when they chipped the implements, and numerous broken and unfinished tools. In the summer of 1937 work was continued from the place where the 1936 activities were stopped and further confirmatory evidence obtained. Additional pits were sunk at new portions of the site during the 1938 season and several areas where fires had been built, animals cut up and cooked, and implements made were revealed (pl. 9, figs. 1 and 2). Most of the bones belong to *Bison taylori*, but a few represent an as yet unidentified deer and a group of small mammals. At some distance from the excavations, yet within the boundaries of the site, a section of mammoth tusk associated with some cut and split bones and charcoal came to light. There were no points or implements associated with these remains, however, hence it cannot be stated definitely that they are contemporaneous with the other materials. The horizon in which they lay was identical with that where most of the excavations have been made, and as other sites have shown that Folsom hunters did kill the mammoth, there seems little doubt that such was the case at the Lindenmeier ranch.

During the summer of 1935 the Colorado Museum of Natural History also conducted excavations at the Lindenmeier site. These consisted of a series of 15 test pits spaced at intervals across the site, approximately at right angles to the line of the main trenches of the Smithsonian party. One of these test holes west of the large trenches penetrated the artifact-bearing stratum where there was a concentration of material. With this as a starting point an area 30 by 30 feet was excavated. This pit yielded most of the specimens obtained by the Denver group. The material thus collected adds to the general fund of information on the site. Mr. Figgins and John L. Cotter, who was in direct charge of the work, made available to the present writer, for study, all of the specimens obtained from their excavations, and Mr. Cotter also furnished a copy of the manuscript that he submitted as a report on the investigations.

Since the fall of 1934 Major Coffin and Judge Coffin, with the assistance of various friends, have carried on a series of independent explorations at different places on the site and have obtained a large number of artifacts to supplement the series collected by the other excavators.

Approximately 6,000 stone implements and a few ornaments, several of carved bone (pl. 10), as well as portions of tools made from animal bones have come from the digging. No human skeletal remains have been found, and no indications of a shelter or habitation have been observed. The general complex of implements consists of characteristically fluted points (pl. 11), snub-nosed scrapers (pl. 12), side scrapers (pl. 13), end scrapers, a variety of cutting edges, drills, flakes with small, sharp points that may have served to mark on bone, rough-flake knives, fluted knives, large blades, sandstone shaft polishers and rubbing stones of the same material. The few bone tools probably represent punches or awls. Most of the stone artifacts are chipped or flaked—there are no polished tools— and show that the lithic component in the material culture was primarily a flake industry, although tools of the core type are found. The latter are mainly hammers and choppers.

Evidence from the digging shows that the occupation level was once an old valley bottom which subsequently was filled in by the wearing away of bordering ridges. At the present time it suggests a terrace above an intermittent tributary to a series of streams that eventually join the South Platte River (pl. 5, fig. 1). This effect has been produced by erosion of the ridges that once bordered the valley on the south. At the time of occupation the valley bottom was dotted with bogs and marshy places. The makers of the implements camped on the slopes above these meadows. During the latter part of their occupancy and for some time subsequent to it climatic conditions were more favorable to vegetation than they

have been in recent times. This is demonstrated by the heavy zone of black soil that occurs in the lower levels of the deposits over most of the site. The artifacts and bones are found just below or in the bottom of this layer (pl. 14, figs. 1 and 2). In this respect there is similarity between the Lindenmeier and other sites where the materials were also present in dark-clay deposits, but in contrast to the others the Lindenmeier stratum does not represent alluvial deposits: it was produced by heavy vegetation. After the abandonment of the location by its human inhabitants an era of erosion set in, and material from the valley walls was washed down across the site. The fill in the valley bottom shows that there have been several alternating periods of erosion and building up between that time and the present (pl. 7, fig. 2). These changes were probably induced by the lowering of the water table resulting from the encroachment of small streams working headward from the south and from a progressive lessening of general precipitation over the area. Dr. Kirk Bryan and Dr. Louis L. Ray, of the Division of Geology, Harvard University, spent four seasons working on the geology of the region in an effort to date the period of occupation. They attacked the problem from the angle of determining the relation of the Lindenmeier Valley to the various terraces of the major drainage streams of the area. This correlation was established after many months of careful survey, and, by the same process of tracing terraces along the main streams back into the mountains, relationship with the various glacial stages was demonstrated. The conclusion reached is that Folsom men lived at the Lindenmeier site while glaciers still lingered in the mountains and when the climate was wetter and colder than now. Although the stage represented is long after the climax of the Wisconsin glaciation, it is still within the Late Glacial and is good evidence for the presence of men in the New World in Late Pleistocene times. From present knowledge it is not possible to give a close estimate of the number of years involved, but the age has been placed at from 10,000 to 25,000 years ago with the probability that it is closer to 25,000.

Present indications are that the Lindenmeier site was not occupied continuously by a large group of people. It probably was an annual summer and fall camping ground visited regularly over a period of years by smaller parties. That the intervals between occupations were not protracted is shown by the homogeneous nature of the layer in which the artifacts are found.[5]

The find at Dent, Colo., which lies some 50 miles southeast from the Lindenmeier site, consisted of mammoth skeletons and two large fluted points. This association is in agreement with that found by

---

[5] Further information on the Lindenmeier site is contained in Bryan, Kirk, 1937; Coffin, R. G., 1937; Roberts, 1935, 1936.

Howard and Cotter in the Clovis-Portales area and indicates that the finding of a portion of a tusk at the Lindenmeier site was not necessarily due to entirely fortuitous circumstances. The digging at Dent was started by Father Conrad Bilgery, S. J., and a number of his students from Regis College, Denver, and was completed by a party from the Colorado Museum of Natural History.[6]

Other sites where implements of the Folsom type are found are located in this same general area. One is near the town of Kersey, Colo., about 7 miles east from Greeley, Colo. It was discovered by F. L. Powars and his son Wayne, of Greeley, and the writer did some work there in the summer of 1936. The other is 18 miles northwest from Fort Collins, about 12 miles southwest from the Lindenmeier, and was found in the fall of 1935 by T. Russell Johnson, of La Porte, Colo. Some digging was done there in the summer of 1936 by Miss Marie Wormington of the Colorado Museum of Natural History. Neither of these two sites is as productive or extensive as the Lindenmeier, but the objects found there are in close agreement with those from the latter.

From the evidence now at hand certain broad generalizations may be made concerning the Folsom problem. No human remains definitely attributable to that phase of American archeology have been found. One skeleton from the Clovis-Portales region was reported as a Folsom man, but there were no accompanying artifacts to show that such was the case. Another purporting to be Folsom came from a bank of the Cimarron River 8 miles east of Folsom. It also had no associated objects that would aid in correlating it with the makers of the fluted points and other implements characteristic of the Folsom complex.[7] Both may be the remains of those people, yet such a conclusion is not tenable without the support of accompanying artifacts because both regions were occupied by other and later Indian groups. Hence, it must be said that so far as his physical characteristics are concerned, Folsom man is still an unknown person. There is no information on the type of shelter he may have used. On the other hand it seems obvious that he was a typical hunter depending entirely upon game—mainly bison, but occasionally the mammoth and a stray camel, deer, and antelope—for his maintenance and sustenance. He no doubt supplemented his preponderant meat diet with wild seeds and "greens" but did not cultivate his own vegetal food. He probably did not settle long in one place but traveled wherever the animals moved in order to support himself. This factor unquestionably is linked with that of the spread of aboriginal man to North America and the question of when that movement began. There would be little incentive to migrate to a region where

[6] Figgins, 1933.

[7] Figgins, 1935; Roberts, 1937.

animals were scarce or absent; consequently, the men must have followed the game, and the routes of travel must have been more or less the same.

A complicating ramification in the study of the problem is that of the glaciation and extent of the ice sheets over North America. Many of the mammals that crossed over from Asia during Pleistocene times seemingly came by way of Bering Strait, either over the ice or by means of a land bridge in that vicinity. Some of them came during interglacial stages, others toward the end of the Late Glacial and in the Early Postglacial. The main pathway from the unglaciated area in central Alaska seems to have been east to the Mackenzie and then southeastward along that river and the eastern slopes of the Rocky Mountains into the Plains. This corridor apparently was open for a time prior to the last glacial stage and then became the first land route available when the glaciers began to melt. Subsequently, a route due south along the Fraser River opened, and the Pacific coast strip also became available for land travel over most of its length. Some of the animals hunted by Folsom men, the mammoth particularly, probably penetrated into the area in interglacial times, because opinion is that elephants and bison were missing in Alaska in Late Glacial and Early Postglacial times, while others undoubtedly migrated with the opening of the cordilleran corridor. Present indications are that it was at the latter stage that the hunters first ventured into this vast New World. Many of the animals that served as game were essentially the same as exist today, but as the people moved toward the south they found and killed forms that are now extinct, such as the mammoth, mastodon, some species of bison, the camel, and the ground sloth. Although these extinct forms are considered as Pleistocene mammals, there appears to be no question but that many of them may have lived on into Postglacial times. For this reason the mere association of man-made tools with bones of such creatures does not necessarily indicate a Pleistocene date. Other complications are brought about by the probability that some forms—the mammoth, mastodon and musk-oxen—followed the retreating glaciers and, when found in some of the more northern districts, are not actually as old as those uncovered in southern localities. However, two of the Folsom sites, Folsom and Clovis-Portales, have been placed at the close of the Pleistocene with mention of the possibility that they really belong within that period, and the Lindenmeier site has been assigned to a phase within the Pleistocene on evidence apart from animal remains. For this reason it becomes increasingly clear that the Folsom hunters must have drifted down along the opening corridor not long after the beginning of the glacial retreat.[8]

[8] Antevs, 1935 b; Johnston, 1933.

Mention should be made of the distribution of fluted points. The type has been known for a long time and variations of it have been found from the Rockies to the Atlantic, from the Plains Provinces of Canada to the Gulf of Mexico. It is represented in collections in numerous museums and in at least one case has been called by another name, the Seneca River point. It did not attract particular attention until the finds at Folsom. This was largely because most of the examples were picked up from the surface and were without definite significance. The main area of concentration for the type lies in a strip that stretches from Alberta and Saskatchewan in the north to New Mexico and western Texas in the south. Smaller centers are found in the eastern and southern States, notably western New York, Ohio, Tennessee, and in a district along the boundary line between central Virginia and central North Carolina. Only a few sporadic examples have been found west of the Rockies and most of them come from two districts in California, one in the southern part of the State and the other in the northern. There are two main classes of fluted points, one represented by the Folsom, Lindenmeier, and similar forms found in the western plains strip along the Rockies, and a larger, more generalized one embodying most of the characteristics but not exhibiting the same degree of skilled workmanship in their manufacture and for the most part lacking the fine secondary retouch along the edges. The latter form is the one with the wide distribution (pl. 15). The question is whether all should be called Folsom points or if there should be some designation that did not carry the implication of equal age. Dr. Howard and the writer have used the terms Folsom-like and Folsomoid to indicate the distinction, but both have been frowned upon by the archeological taxonomists. H. C. Shetrone of the Ohio State Museum has suggested that they be definitely termed Fluted Points as a class and the various forms then be more specifically designated by place names such as Folsom, Lindenmeier, Clovis, et cetera. This proposal has considerable merit and would remove much present confusion. However, a committee appointed at the symposium on early man decided that the name Folsom should be applied to all. Such being the case it would seem that definite qualifiers should be used, as in the case of Mr. Shetrone's suggestion, and the various examples be known as Folsom-Folsom, Lindenmeier-Folsom, Ohio-Folsom, or California Folsom.

The significance of the fluted points occurring east of the Mississippi River is open to question. There is still no evidence suggesting their possible age or place in the main archeological picture. The vast majority are surface finds and although there seem to be several centers, as mentioned previously, where they are picked up in comparatively large numbers, nothing has come to light that would indicate their relationship to the cultural remains present in those

areas. The fact that the eastern examples bear a striking resemblance to those in the West does not make them of equal antiquity. They may represent a survival of a highly specialized implement in later horizons. Some students take a different view and regard the individuality of the form together with its apparent absence from the recognized complexes in the East as a manifestation of its greater age. On the basis of the distribution concept as an index to age—a theory substantiated in some respects by evidence that tends to indicate that there is a correlation between type and distribution, so that the larger the area covered the older the form—the eastern examples would indicate more antiquity than the western. But until specimens are found in association with fauna comparable to that in the West and accompanied by other implements now known to belong to the Folsom complex, conclusions must be withheld. The question becomes more complicated when it is recalled that the Folsom implement makers no doubt chipped a variety of sizes and qualities of points for use in hunting different kinds of game, and the larger forms may merely represent those intended for big animals.

The California occurrences raise a number of questions. There apparently is so marked a gap between them and the major centers of the type that the problem of the relationship is difficult to solve. Furthermore, many of the purported Folsom points from that region are so nondescript in form that it requires stretching of the Folsom-like category to the utmost to include them. In only a very few cases is there an approximation of similarity to the Folsom-Folsom or Lindenmeier-Folsom specimens. This matter of identification, however, is one that has proved troublesome in all parts of the country, and there has been a tendency to include points with a basal thinning, not an actual facial fluting, in the Folsom classification. An explanation for the presence of materials attributable to the Folsom complex in California is hard to find in the light of present knowledge. They may have worked westward from the southern plains area, but traces of such a movement are scarce, and suggestions that the reverse was the case, that the Folsom hunters worked east from southern California and thence upward into the plains, seem entirely unwarranted in the light of knowledge of the migration of the animals that formed the chief source of sustenance and the occurrence of materials in that area. It is more likely that the Pacific coast was reached by groups drifting down the Fraser River corridor after it had opened. Coming from the upper plains reservoir of hunting peoples, they could well have possessed similar implements. While too little is known as yet concerning the problem to make any definite statements, it may be mentioned that in view of the indications that the Fraser route opened subsequent to that of the western plains corridor, the Cali-

fornia remains may represent a somewhat later phase and for that reason show some differences.

In closing, attention should be called to the fact that there are other traces of early occupancy in portions of the plains area, particularly in Minnesota and Texas. In some cases there are indications that the remains may antedate those of the Folsom complex, in others that they are contemporaneous with it. Although detailed consideration of these occurrences is not pertinent to the present discussion, it is essential to mention them because they have significance in connection with the study of early man in America, and the matter of their relationship to or bearing on the Folsom problem is a phase of the subject still to be studied.

LITERATURE CITED

Antevs, Ernst

1935 a. The occurrences of flints and extinct animals in pluvial deposits near Clovis, N. Mex. Pt. 2, Age of the Clovis lake clays. Proc. Acad. Nat. Sci. Philadelphia, vol. 87, pp. 304–312.

b. The spread of aboriginal man to North America. Geogr. Rev., vol. 25, No. 2, pp. 302–309, April.

Brown, Barnum

1929. Folsom culture and its age (with discussion by Kirk Bryan). Bull. Geol. Soc. Amer., vol. 40, pp. 128–129.

Bryan, Frank

1938. A review of the geology of the Clovis finds reported by Howard and Cotter. Amer. Antiquity, vol. 4, No. 2, pp. 113–136, October.

Bryan, Kirk

1937. Geology of the Folsom deposits in New Mexico and Colorado. *In* Early Man, as depicted by leading authorities at the International Symposium, Academy of Natural Sciences, Philadelphia, March 1937, pp. 139–152. J. B. Lippincott Co., London.

Coffin, Roy G.

1937. Northern Colorado's first settlers. Publ. by Colorado State Coll., Fort Collins.

Cook, H. J.

1927. New geological and paleontological evidence bearing on the antiquity of mankind. Nat. Hist., Journ. Amer. Mus. Nat. Hist., vol. 27, No. 3, pp. 240–247, May–June.

Cotter, John L.

1937. The occurrence of flints and extinct animals in pluvial deposits near Clovis, N. Mex. Pt. 4, Report on excavation at the gravel pit, 1936. Proc. Acad. Nat. Sci. Philadelphia, vol. 89, pp. 1–16.

1938. The occurrence of flints and extinct animals in pluvial deposits near Clovis, N. Mex. Pt. 6, Report on field season of 1937. Proc. Acad. Nat. Sci. Philadelphia, vol. 90, pp. 113–117.

Figgins, J. D.

1927. The antiquity of man in America. Nat. Hist., Journ. Amer. Mus. Nat. Hist., vol. 27, No. 3, pp. 229–239, May–June.

1933. A further contribution to the antiquity of man in America. Proc. Colorado Mus. Nat. Hist., vol. 12, No. 2.

1935. New World man. Proc. Colorado Mus. Nat. Hist., vol. 14, No. 1.

HOWARD, EDGAR B.

1935 a. Evidence of early man in North America. Mus. Journ., Univ. Mus., Univ. Pennsylvania, vol. 24, Nos. 2–3, pp. 61–175.

b. The occurrence of flints and extinct animals in pluvial deposits near Clovis, N. Mex. Pt. 1, Introduction. Proc. Acad. Nat. Sci. Philadelphia, vol. 87, pp. 299–303.

JOHNSTON, W. A.

1933. Quaternary geology of North America in relation to the migration of man. *In* The American Aborigines, their origin and antiquity. 5th Pacific Sci. Congr., Canada, 1933, pp. 11–45.

ROBERTS, F. H. H., JR.

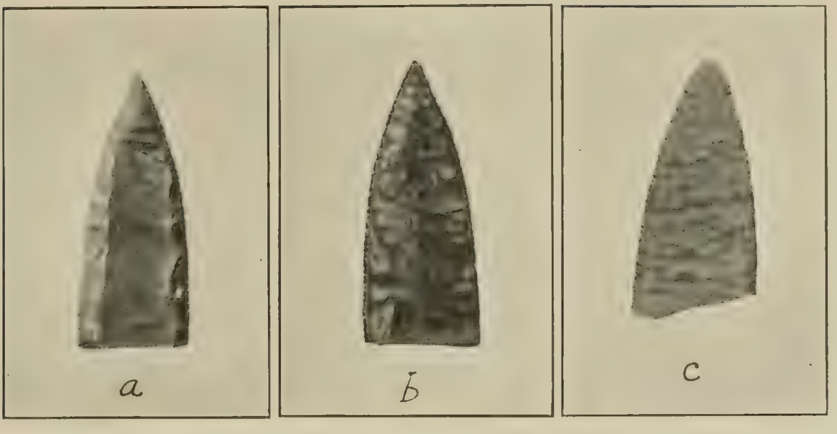
1935. A Folsom complex: preliminary report on investigations at the Lindenmeier site in northern Colorado. Smithsonian Misc. Coll., vol. 94, No. 4.

1936. Additional information on the Folsom complex: report on the second season's investigations at the Lindenmeier site in northern Colorado. Smithsonian Misc. Coll., vol. 95, No. 10.

1937. New World man. Amer. Antiquity, vol. 2, No. 3, pp. 172–177, January.

STOCK, CHESTER, and BODE, F. D.

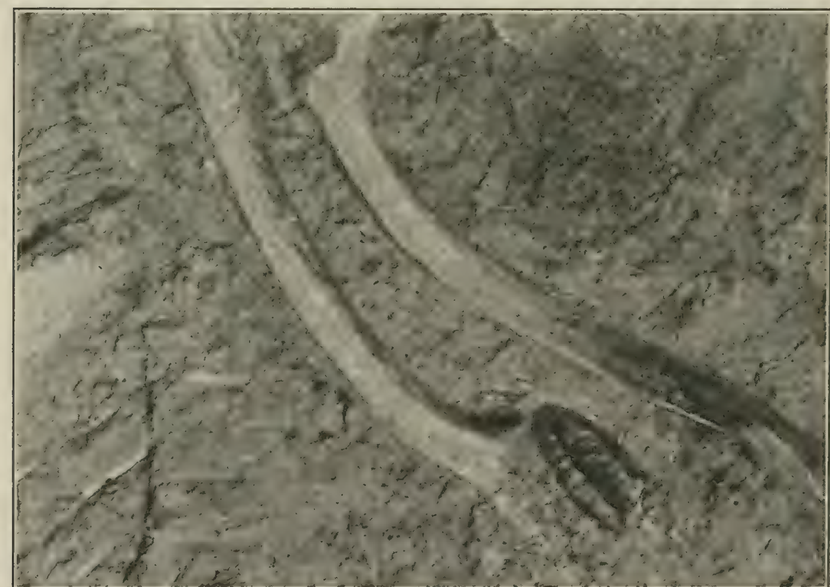
1936. The occurrence of flints and extinct animals in pluvial deposits near Clovis, N. Mex. Pt. 3, Geology and vertebrate paleontology of the later Quaternary near Clovis, N. Mex. Proc. Acad. Nat. Sci. Philadelphia, vol. 87, pp. 219–241.



1. *a*, *b*, *c*, original points from Folsom pit. *a* and *b*, different sides of same specimen.

2. Fragment of stone in place near bone and portion of point that fits small piece. (Pictures on this plate courtesy of Colorado Museum of Natural History).

1. Folsom pit in summer of 1927. Point and bones in situ at left of standing figure. (Photograph by author.)



2. Point and bison ribs in situ. (Photograph courtesy of Colorado Museum of Natural History.)

1. General view of "blow-out" between Clovis and Portales.

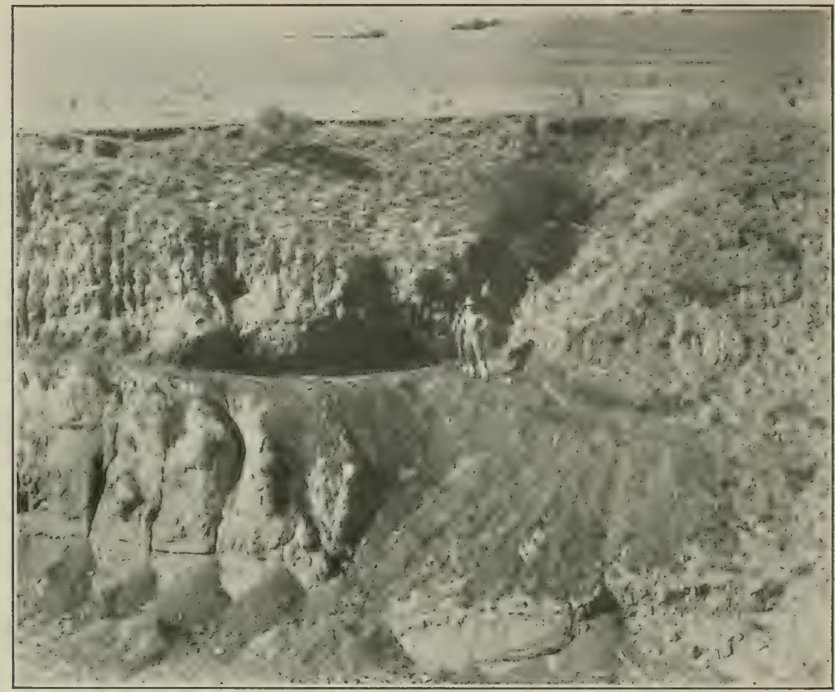
2. Mammoth tusk weathering out of old lake bed. (Pictures on this plate courtesy of Dr. E. B. Howard.)

1. Part of trench at Clovis sites where two mammoth skeletons and bison were uncovered in direct association with Folsom points. (Picture courtesy of Dr. E. B. Howard.)

2. One characteristic type of Yuma points.

1. Looking east across Lindenmeier site. Cross indicates excavation area. (Photograph by author.)

2. View across Lindenmeier site toward the southwest. Excavations in central portion of picture. (Photograph by author.)



1. Deep pit in ravine bank at beginning of investigations. (Photograph by author.)

2. Large trenches cutting across site toward deep pit in ravine bank. (Photograph by author.)

1. Sifting material at lower end of trench leading into pit. (Photograph by author.)

2. End of large trench. Workman standing on level where artifacts were found. (Photograph by author.)

1. Articulated foreleg of bison in situ at Lindenmeier site. (Photograph by author.)

2. Tip of projectile point lodged in bison vertebra.

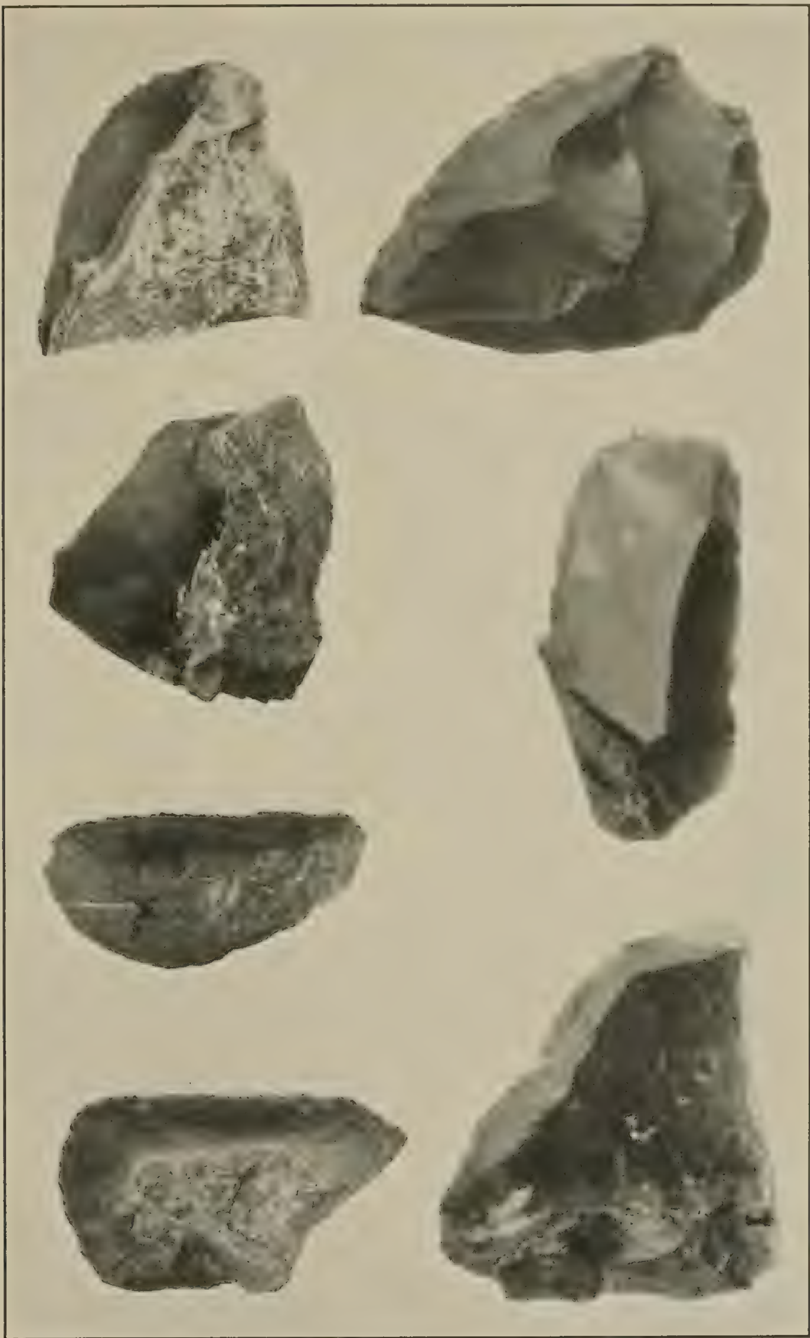
1. Workman uncovering bone fragments and stone tools at Lindenmeier site. (Photograph by author.)

2. Split bones and stone implements in situ. Small numbers indicate artifacts. (Photograph by author.)

ORNAMENTED BONE SCRAPS FROM LINDENMEIER SITE. (ACTUAL SIZE.)

FOLSOM POINTS FROM THE LINDENMEIER SITE. (ACTUAL SIZE.)

SNUB-NOSED SCRAPERS FROM THE LINDENMEIER SITE. (ACTUAL SIZE.)



SIDE SCRAPERS FROM THE LINDENMEIER SITE. (ACTUAL SIZE.)

1. Bones and stone objects at base of heavy soil zone. (Photograph by author.)

2. Workmen removing bone scraps and stone implements from layer below heavy soil zone. (Photograph by author.)

TYPICAL FORMS OF POINTS FOUND IN SOUTHERN AND EASTERN STATES.
(ACTUAL SIZE.)

THE ROMAN ORIENT AND THE FAR EAST [1]

By C. G. Seligman

[With four plates]

Compared with the civilizations of Egypt and the Near East, Chinese civilization as we know it is not of great age. Authentic history does not begin until about the ninth century B. C. (a commonly accepted date is 841 B. C.), nor have we archeological finds that we can reasonably date prior to the thirteenth or fourteenth century B. C., though the beauty and mature style of the earliest known bronzes indicates a history of at least hundreds of years before this.

Figure 1 illustrates the time-relations of China and the Near East. In spite of its magnificent bronzes and graved bones, we know little of the Shang-Yin dynasty, which in date comes near to coinciding with the 18th dynasty of Egypt, while the Shang-Yin script is still somewhat primitive, indicating perhaps a period of no more than a few hundred years from an unknown pictographic origin.

The above chronology applies only to northern China, where Chinese civilization arose; indeed it did not reach south of the Yangtze until a few centuries B. C. The civilization of Japan is even younger, and is now generally accepted as not more than some 2,000 years old. Thus the earliest contacts between West and East were between the Roman Orient and China.

In order to have more space to discuss historic contacts—extending over something more than 1,000 years (between 200 B. C. and A. D. 900)—I shall deal very briefly with prehistoric contacts and refer only to the socketed celt. This highly specialized form of axe is one of the most characteristic implements of the Late Bronze Age (c. 1300–900 B. C.) of central and eastern Europe.[2] Using geological terminology, we may look upon it as the type-fossil of its age and zone of distribution. It is found over the whole of northwestern, central, and especially northeastern Europe; it occurs in Italy, but not in Greece, and is

[1] The Lloyd-Roberts lecture for the year 1935, delivered before the Royal College of Physicians. Reprinted by permission, with slight revision, from Antiquity, vol. 11, No. 41, March 1937.

[2] Déchelette, Manuel d'Archéologie, vol. 2, p. 106, Paris, 1910. In eastern Russia the date given by G. von Merhart, Bronzezeit am Yenissei, p. 16, Vienna, 1926, is from 1000 to 400 B. C.

114728—39——36

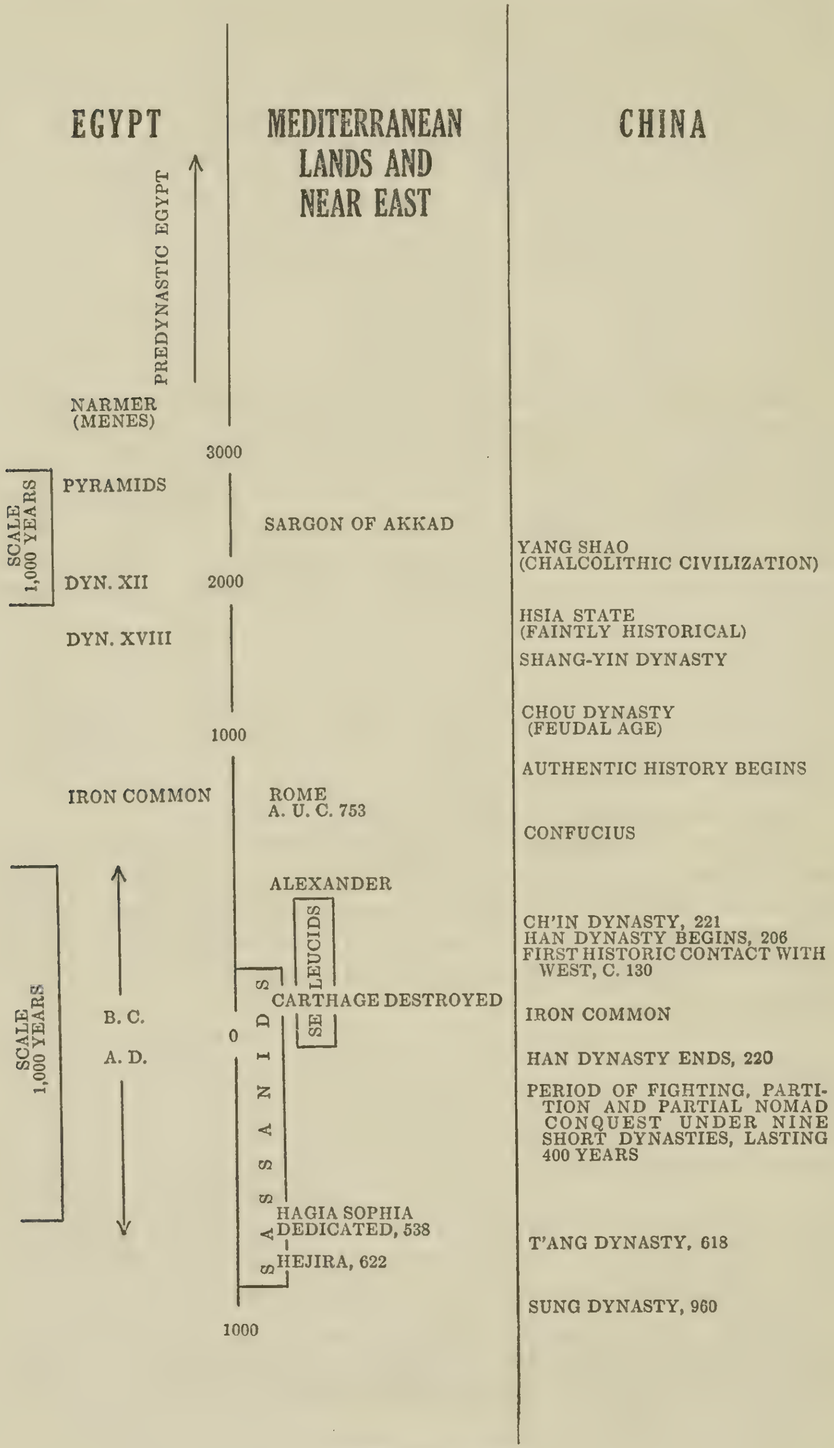


FIGURE 1.—Time chart.

absent from Africa; no specimen has ever been recovered from an Egyptian tomb, nor does it occur in Asia Minor, Persia, or India. The socketed celt passed along no definite or organized trade route—there is good historical evidence to show that the silk route was not organized in its entirety until the second century B. C.—but we may picture it as borne eastward from southern Russia on a wide front across the Urals, specimens passing from hand to hand among the pastoral nomads of Siberia, until here and there, as at Minusinsk, a metallurgical center came into existence, the manufactured products

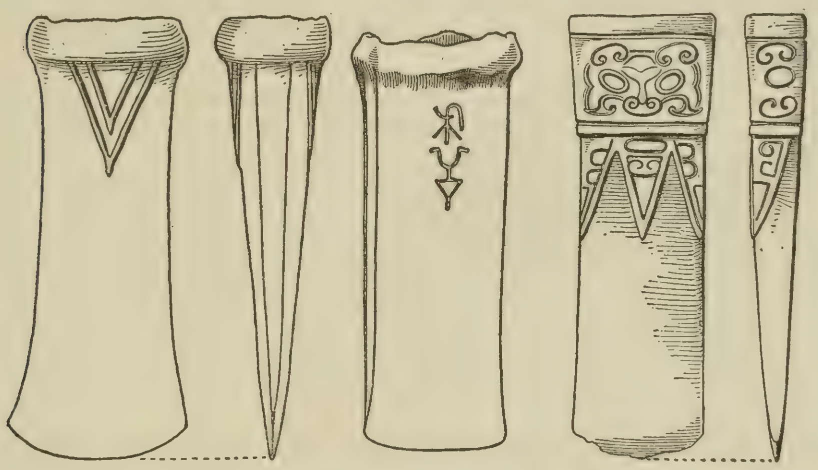


FIGURE 2.—Socketed celts.

being carried far and wide north and east of the great mountain ranges of Central Asia.[3]

Figure 2 represents three socketed celts. The one on the left is from Hungary and that in the center (both in the British Museum) from China, as is that on the right. The first character on the central specimen Professor Yetts informs me is clearly *ho*, "growing grain."

From these early contacts with Siberia and the West, we turn to that great track, nearly 5,000 miles long, which, crossing mountain, steppe, and desert, constituted the highway along which Ariadne's silken thread joined the farthest East with Antioch, the most important city of the Roman Orient.

This route was first organized throughout its length in the second century B. C., but long before this lapis lazuli was reaching Ur, and

[3] When this lecture was given I held that the socketed celt did not reach China until the seventh or sixth century B. C. We now know that the actual date was several hundred years earlier, i. e., in the twelfth or eleventh century B. C., at the end of the Shang-Yin dynasty. There exist specimens from An-yang, the capital of the later kings of that dynasty, which can only be dated to that period of bronze decoration to which Professor Yetts has applied the term "First Phase," historically the latter part of the Shang-Yin and early part of the Chou dynasties (Antiquity, vol. 12, 1938).

For a general discussion of the passage of the socketed celt from Europe to China see The Journal of the Royal Anthropological Institute, vol. 50, 1920.

even predynastic Egypt (i. e., 3000 B. C. and earlier). There can be no doubt that this rare mineral was mined in eastern Afghanistan, and reached Mesopotamia and Egypt, passing, as we may infer, over what was later to be the organized western third of the trade route.[4] Besides this, commonsense indicates that from early times hillmen and dwellers on the plains must have exchanged goods along its course, and pastoral nomads have raided and traded with the sedentaries. But it was not until China's discovery of the West that a highway which was to join Pacific and Atlantic was brought into being and organized to constitute a single whole, as definitely intended for the far movement of goods and men as is its modern successor, the Trans-Siberian Railway.

It must, however, be remembered that while the silk route across Asia is of special interest on account of the discoveries by Stein and others that have been made along its course, the use of the monsoons from the first century A. D. as a means of direct passage from the Red Sea to India was of even greater economic importance. Rome's trade with India was always greater than with the Far East; part of the silk she received was brought by sea in ships which picked up their wares in ports as far east as Tongking and Burmah, as well as in the nearer ports of western India such as Muziris (the modern Cranganore). It is significant that no hoards of Roman coins have been found in China as they have in India.[5]

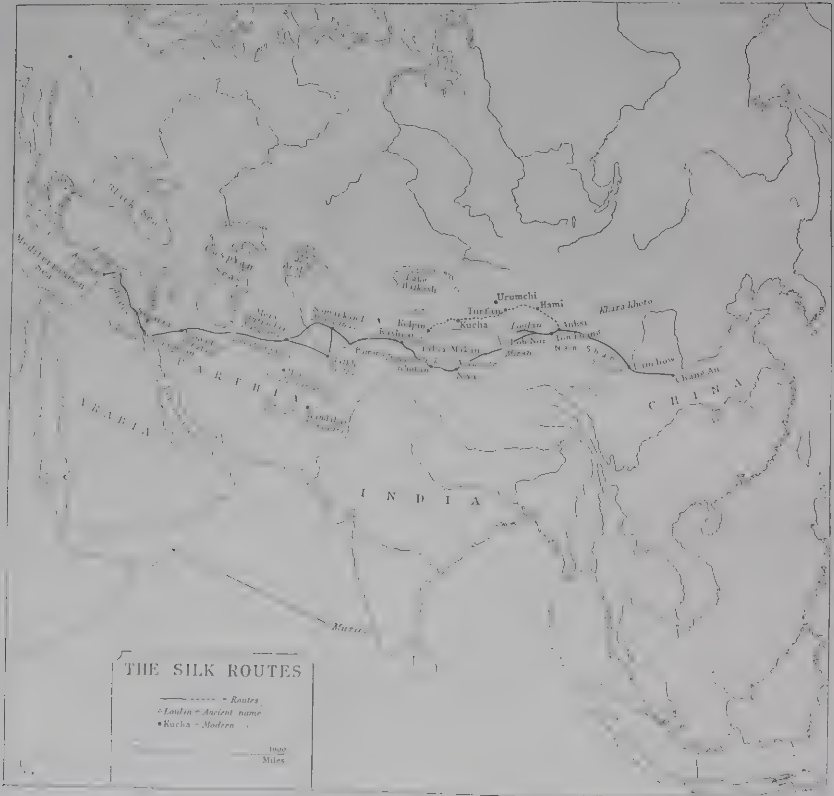
The various stages of the highway have been often described, indeed the route was mapped with amazing accuracy—considering the then state of geographical studies—in a work dedicated to Napoleon [6] by the learned Joseph Hager of Pavia University, who pictures the actual arrival of a Greek caravan at Sianfu, while within the last few years G. F. Hudson has given an excellent survey in his important work, Europe and China. In what follows I have drawn largely on his account, but have considered it convenient to divide the highway into three main sections—eastern, middle, and western—rather than to consider it in four sections depending on political factors, as he does.

The eastern section, which may be regarded as starting either at Ch'ang-an (the Han capital) or at Lan Chow in western Kansu, i. e., the extreme northwest of China, passes south of the westernmost extension of the Great Wall but north of the Nanshan range, westward

[4] Gregory, J. W., The story of the road, pp. 33–34, 1931; also Lucas, A., Ancient Egyptian materials and industries, pp. 347, 348, 1934.

[5] The Indian trade, and the sea-borne trade from the Far East which traveled up the Red Sea, is discussed at length in an excellent work by E. R. Warmington entitled "The commerce between the Roman Empire and India," (Cambridge, 1928). My statement with regard to Roman coins may not be quite accurate. Professor Yetts draws my attention to a paper by Bushnell (Journ. Peking Oriental Soc., vol. 1, No. 2, 1886) recording the discovery of 16 Roman copper coins dating from Tiberius to Aurelian, made some 50 or 60 years earlier in Shansi, about 80 miles from T'ai yuan fu.

[6] Description des Médailles Chinoises du Cabinec Impérial de France, précédée d'un essai de Numismatique Chinoise, avec des éclaircissemens sur le commerce des Grecs avec la Chine * * * Paris, an XIII=1805.



114728—39 (Face p. 551)

FIGURE 3.

across Sinkiang (Chinese Turkestan), skirting the Tarim Desert either north or south to reach Kashgar (Issedon Scythica), the gate of the Pamirs. Kashgar is some 1,500 miles from Lan Chou, and Turfan, the region of Stein's great discoveries, lies roughly halfway between the two cities.

The middle section crosses the Pamirs to reach Merv (Antiochia Margiana) by alternate routes, via Samarkand (Marakanda) or Balkh (Bactra).

From Merv the western section ran west and south across northern Iran to Hecatompylos and Hamadan (Ecbatana) to Seleucia-Ctesiphon just below the modern Baghdad, crossing the Euphrates at Zeugma where there was a Roman legionary camp, and thence to Antioch, whence the goods were distributed through the Empire.

This is no place to discuss the ethnology of the peoples along the trade route, though variation in cultural habit must necessarily have greatly influenced commerce along the highway. West of the Pamirs the inhabitants may in a general way be called Iranian; east of this it would perhaps be natural to expect a Mongol or at least predominantly Mongoloid population, but this is not so. The careful analysis by T. A. Joyce of the measurements and photographs brought back by Stein indicates that east of the Pamirs the ethnic type is predominantly Alpine, with considerable Turki admixture and traces of Turki and Afghan, definitely not Mongol.[7] This may to some extent account for the hold that various items of western thought and habit achieved along the trade route, though too much can be made of the reputed Chinese unwillingness to adopt foreign ideas and practices; for, as noted later, the T'ang period—perhaps that of China's greatest brilliance—was marked by the influx and ready acceptance of foreigners and of foreign (Western and Indian) ideas.

Although there were many factors that tended to the early utilization of the silk route by the Chinese and emphasized their determination to keep it open, it cannot be too strongly stressed that it was neither desire for geographical knowledge nor love of conquest or of gain that dictated China's exploration of the West. It was in the first place due to sheer military necessity, the same need that led to the building of the Great Wall in order to counter the attacks of the barbarians of the North. These were the Hsiung Nu nomads, a Turki-speaking stock, identified with the Huns who invaded Europe a few centuries later. Under the Emperor Wu (141–87 B. C.) the struggle, waged intermittently for a couple of centuries, became a desperate contest, into which was thrown the full strength of the Empire. The hope of finding assistance in the West and so outflank-

[7] Joyce, T. A., On the physical anthropology of the oases of Khotan and Keriya, Journ. Roy. Anthrop. Inst., vol. 33, 1903; and Notes on the physical anthropology of Chinese Turkestan and the Pamirs, op. cit., vol. 42, 1912.

ing the Hsiung Nu was the primary purpose of that western journey upon which Wu sent his general, Chang Ch'ien, thereafter maintaining regular touch with Iranian lands.

Hand in hand with the determination to repulse the Hsiung Nu, went the Chinese desire for a supply of those fine Iranian horses which in China were called "blood-sweating horses," fabled to be the offspring of a heavenly steed, for it was at this time that the Chinese, in response to Hsiung Nu attacks from the North, were developing a new technique of warfare in which cavalry played the preponderant part. The fodder of these noble beasts was alfalfa (*Medicago sativa*), and Chang Ch'ien, being a man of judgment, not only brought back the horses but also alfalfa seeds, leading to the rapid diffusion of the plant through northern China. The best horses appear to have come from Ferghana, now the eastern portion of Russian Turkestan, where alfalfa still yields four or five crops a year and is cultivated up to a height of 5,000 feet.[8]

Another gift brought by Chang Ch'ien from the West was the grape used in Ferghana to make wine; the vine was, however, cultivated for centuries in its new home before the Chinese made wine from it, first apparently in the seventh century.[9]

It was Chang Ch'ien's quest for the "blood-sweating" horses that established the first contacts between China and the Mediterranean world, for the Ta Yüan, the owners of the coveted horses, were the inhabitants of Sogdiana (between Oxus and Jaxartes), while Ta Hsia, the country newly settled by the Ta Yüeh-chih, was Bactria, both occupying the furthest extremity of the great Bactrian-Sogdian satrapy of Alexander's Empire. Although at this time the Seleucids had lost their outlying possessions, especially in the East,[10] even the remotest territories had been so thoroughly permeated by Hellenistic influence that they retained something of Hellenism long after this period, though exposed to the enmity of the rising Parthian Empire.[11]

Chang Ch'ien's report has been preserved, perhaps in his own words. Mr. Fitzgerald's translation runs as follows:

> Ta Yuan [Ferghana], the people are sedentary [not nomads] and cultivate the soil. They have many superb horses, which sweat blood when they perspire. There are cities, houses, and mansions as in China. To the northeast is the country of the Wu Sun (the Ili Valley], to the east is Yu T'ien [Kashgaria]. West of Yu T'ien the rivers flow westward into the Western Sea [the Caspian and

[8] Laufer, B., Sino-Iranica, p. 210, Chicago, 1919. Several aspects of the quest for the superior horse are investigated by Yetts (The horse, a factor in early Chinese history, Eurasia, Septentrionalis Antiqua, vol. 9, pp. 231–255, 1934).

[9] Laufer, op. cit., pp. 221 et seq.

[10] In 255 B. C. or thereabouts, Bactria revolted under Diodotus and gradually became independent, Diodotus II becoming king some time before 227 (Cambridge Ancient History, vol. 7, pp. 719, 720).

[11] The Parthians dated their era from the year 247 B. C. (loc. cit.). In order to emphasize the high degree in which Hellenistic influence was present in the Satrapy, it is worth remembering that both Herat and Kandahar when founded bore the name of Alexandria. I may also refer to a passage by Rostovtzeff bearing on this point (Cambridge Ancient History, vol. 7, pp. 157–8).

Aral, Chang Ch'ien did not distinguish between the two]. From Yü T'ien eastward the rivers flow to the east into the salt swamps [the Tarim river system]. From these swamps the waters flow underground until they reappear as the source of the Yellow River. From the salt swamp to Ch'ang An, the distance is 5,000 Li. The Right horde of Hsiung Nu live between the salt swamps and the Great Wall of Lung Hsi [Kansu]. The Wu Sun [Khirgiz], K'ang Chu, and Yen Ts'ai, who are northwest of the K'ang Chu, and Ta Yüeh Chi, are nomads with customs similar to the Hsiung Nu. Ta Hsia [Bactria] is southwest of Ta Yüan and has similar customs. When your servant was in Ta Hsia he saw large bamboos and cloth of Shu [Szechuan]. When he asked the people of Ta Hsia how they obtained these things they told him that their merchants bought them in Shên Tu [Sind, India], which is a country several hundred li southeast of Ta Hsia, and is a sedentary nation, like Ta Hsia. Both Ta Hsia and Ta Yüan are tributary to An Hsi [Parthia, so called from the dynasty of Arsaces]. So far as your servant could judge Ta Hsia is 12,000 li [4,000 miles] from China. As it is northeast of Shên Tu, this kingdom cannot be so far from China.[12]

Distances are exaggerated (the li is a third of a mile) and the source of the Yellow River incorrectly stated, but apart from these errors the report is a plain statement of fact. Chang Ch'ien had, however, so thoroughly experienced in his own person the difficulties of the northern route that he persuaded the Emperor to seek to approach the West overland via India, a reasonable enough suggestion at a time when the extreme difficulty of the country between Yunnan and Burmah was unknown; for even at the present day the deep gorges of the Mekong and Salween rivers make this one of the most inaccessible parts of the earth's surface. When it was realized that this route was impossible, interest once more centered on the northern route, and several embassies reached Ta Yüan. For a long time the ruler of this state resolutely refused to hand over any of his celebrated horses, and little progress was made until Chinese envoys seized some of the best horses and with them set out for China, only to be ambushed by the Yüan, who killed the Chinese and recovered the horses. An attempt to revenge this insult resulted in the defeat of a Chinese army, and it was not until a further army was despatched that an agreed peace was made (102 B. C.), one of the terms being that the Chinese received several of the finest horses of Ta Yüan and a large number of inferior quality.

Some years after the death of the Emperor Wu there came a split in the ranks of the Hsiung Nu, whose northern and southern hordes quarrelled and so weakened each other that the southern leader did homage at Ch'ang-an. Chinese vigilance in the west relaxed, and war broke out again during the reign of Han Ming Ti (A. D. 58–77), who was forced to realize that Turkestan must again be brought under Chinese influence. In A. D. 73 Pan Chao, a really great general and administrator, began his career in Turkestan, though it was not until

[12] Fitzgerald, C. P., China: a cultural history, pp. 178–9, 1935.

A. D. 77 that he was given a free hand. His policy was to use native levies of what we should now call "friendlies," with a stiffening of experienced Chinese officers and soldiers:

For the next seventeen years Pan Chao carried out this plan with unbroken success. One by one the kings of the Turkestan oases were reduced to obedience, until the whole Tarim Valley was under the peaceful rule of the Chinese viceroy. In A. D. 97, after reducing the last contumacious prince, Pan Chao crossed the T'ien Shan Mountains, and with an army of 70,000 men advanced unopposed to the shores of the Caspian Sea. Never before, and never since, has a Chinese army encamped almost on the frontiers of Europe. The whole stretch of country between the T'ien Shan and the Caspian submitted to the Chinese without fighting. More than fifty "kings" acknowledged Chinese overlordship and sent their heirs as hostages to Lo-yang.[13]

East to West the highway essentially carried silk, and, to a much smaller extent, furs. The quantity of silk carried was very large; Hudson, referring to the age of the Antonines, i. e., the middle of the second century A. D., writes—no doubt with some little exaggeration—of silken fabrics being "well nigh as familiar in Londinium as in Lo-yang".[14] We have little knowledge of the goods carried eastward in exchange; we do not hear of any particular product of the Near East being exported in large quantities, and what records we have suggest that the Roman Empire, at any rate in the early centuries A. D., in the main paid for its silk in gold. A discovery by Stein enables us to appreciate how thoroughly the trade was organized on the Chinese side. On his 1918 expedition he found two strips of undyed cream-colored silk in one of the refuse heaps adjoining a post on the old Chinese *limes* west of Tun-huang. The silk could be dated by other objects in the heap to between A. D. 67 and 137. Of this happy find Stein writes that one strip "bears the ink impression of a Chinese seal, not yet deciphered, and by the selvages retained at both ends is shown to have come from a piece or roll of silk which had a width of about 19.7 inches or 50 centimeters." The other strip, 12½ inches long and incomplete at one end, bears a Chinese inscription read by M. Chavannes * * * "A roll of silk from K'ang-fu in the kingdom of Jên-ch'êng; width 2 feet and 2 inches; length 40 feet; weight 25 ounces; value 618 pieces of money".[15]

Here, then, on a roll of silk of middle or late Han times prepared for export we have precise indications of its origin, dimensions, weight, and price, while exploration at Loulan provided further evidence that a width of about 50 cm was a standard export size.[16]

Yet in spite of the regular import, which went on for centuries, it is difficult to quote a single example of Chinese silk discovered in

[13] Fitzgerald, op. cit., p. 191.

[14] Hudson, G. F., Europe and China, p. 91, 1931.

[15] Stein, Aurel, Central Asian relics of China's ancient silk trade, Asia Major. Hirth Anniversary Volume, p. 368, 1923. See also Serindia, pp. 373, 374, 1921.

[16] Stein, Serindia, loc. cit., and pl. 37.

Europe or the Near East.[17] The magnificent early medieval silken textiles that we find in church and cathedral treasuries are not of the Far East but have been woven in Roman or in Persian lands. In the latter, weaving attained an intense activity, indicating access to large quantities of raw silk. Though it was not until the sixth century A. D. that the eggs of the silk moth (*Bombyx mori*) were brought to Byzantium, in Persia the silk-weaving industry appears to have been in a flourishing state in the fourth century.[18] Once silk became common, fabrics bearing typical Sassanian designs were exported eastward in considerable bulk. It is only necessary to look at the plates in Stein's Serindia, portraying silks discovered in Chinese Turkestan, to be convinced of this; indeed they became so popular that the Chinese produced figured silks in typical Sassanian style. The most striking evidence for this is the celebrated "hunter" silk of the seventh-eighth century from the treasure of the Horiuji Monastery at Nara in Japan (pl. 1). The composition is typically Persian, but the fabric was woven in China and seals with Chinese characters are seen on the hindquarters of the horses, in place of the Sassanian star.[19] From Tun-huang, Stein has figured a number of silks of great beauty, showing confronted animals in Sassanian style but with Chinese modifications. Two head-pieces for banners, figured in Serindia (pl. 64), constitute particularly instructive examples of the adaptation of a western textile motif by Chinese hands; this silk is definitely hybrid, containing both obvious Sassanian and Chinese motifs. The design is composed of large circular medallions separated from each other by lozenge-shaped masses of elaborate foliage which almost fill the background. The outer part of the medallions is occupied by a double circular border with patterns of spaced elliptical rosettes outside and quatrefoils inside. All this is distinctly Sassanian in type, but instead of the interior of the medallion being taken up by confronted animals it is occupied by four pairs of geese, quite naturalistic in treatment, disposed round a central somewhat stylized floral element. The geese are Chinese in treatment, so much so indeed that they immediately recalled to me the birds inlaid on one of the most beautiful of the lacquer boxes in the Shōsō-in. This silk was probably woven in China proper.

[17] This is, perhaps, scarcely true at the present day, though it was so a couple of years ago. A very few pieces of silk judged to be of Chinese weave have been discovered in the West; work recently carried out at Palmyra—the great caravan town northeast of Damascus on the northern edge of the Syrian and Arabian desert—appears to have produced some examples (R. Pfister, Textiles de Palmyra, Paris, 1934), and it has recently been suggested that a piece of fifth century silk derived from a Rhine cathedral and now in Berlin may have been woven in China (V. Sylvan, Eine Chinesische Seide mit spätgriechschen Muster aus dem 5. bis 6. Jahrhundert, Ostasiatische Zeitschrift, n. s., vol. 11, pp. 22, 27, 1935.

[18] Dalton, O. M., Byzantine art and archeology, p. 584, 1911.

[19] The "hunter" type is one of those popular Persian designs in which a mounted hero is shooting wild beasts, "the whole framed in a medallion and repeated over the surface, the medallions being interlaced or connected by small tangent circles, while the interspaces are filled with formal foliage. The huntsman is usually duplicated so that the composition is symmetrical, the two figures being usually back to back, but turning inwards to release the arrow" (O. M. Dalton, op. cit., pp. 590-91).

Besides the heavy export of gold already alluded to, and in spite of the high rate of destruction which the lapse of 2,000 years entails, we have definite evidence in specimens surviving to our own time of the export from the Roman Orient of at least one kind of luxury article, namely glass. Apart from beads, concerning which I shall have more to say later, we can recognize nearly a dozen pieces of early "Mediterranean" [20] glass still existing in Korea, China, and Japan, and Stein found many fragments of glass (apparently Roman) during his excavations. Realizing when on a visit to the Far East a few years ago that glass might constitute an interesting feature of the incoming trade from the West, I took the opportunity of noting all the specimens of western glass that I was able to see, and also made inquiries as to the occurrence of glass beads and pendants and other small objects believed by the Chinese to be of considerable age. The results were sufficiently encouraging to lead to further study, and with the assistance of a number of kind friends—all specialists in some aspect of the subject, whether in archeology or chemistry—it has been possible to reach certain interesting conclusions.[21]

In 1929, in Korea, I was shown two perfect glass vessels, pronounced by experts to have been made in the Roman Orient (no doubt Syria) about the fourth century or a little later, excavated by the Japanese from the royal graves of the kings of Silla, the kingdom which for at least seven centuries from about 100 B. C. occupied what is now southeastern Korea. One of these vessels, for the photograph of which I am indebted to Prof. S. Umehara, is represented in plate 2, figure 1. These two specimens, with a large dish of "Roman," i. e., probably Syrian, glass (pl. 2, fig. 2) of the third–fifth centuries A. D., found in China (Honan) and now in the possession of Mrs. Margot Holmes, are probably the earliest western glass vessels hitherto dis-

[20] We know nothing of the glass-making sites in classic lands in classic times. I therefore use "Mediterranean" as a convenient term for glass made by the old civilizations which existed on its shores or in vital contact with it, including Mesopotamia.

[21] I would especially acknowledge my indebtedness to Mr. Horace Beck, whose unrivaled knowledge of beads and early glass has been invaluable, as well as to Mr. R. L. Hobson, Mr. Bernard Rackham, Prof. Perceval Yetts, and Mr. G. Eumorfopoulos for much kindly advice. On the chemical side I have had the advantage of unlimited help from the Scientific Laboratories of the Courtauld Institute of Art (University of London), so that it gives me the greatest pleasure to thank Prof. W. G. Constable, the Director of the Institute, and Dr. P. D. Ritchie, lately Head of the Scientific Department, for their interest and assistance. I am also greatly indebted to the Rt. Rev. Bishop White, formerly Bishop of Honan, for specimens and advice. I should also like to acknowledge help given by Dr. Otto Samson, formerly of the Ethnographic Museum, Hamburg, while for permission to reproduce figures 11 and 12 I must thank the authorities of the British Museum and of the India Office, respectively.

covered in the Far East.[22] Some three centuries later are the half-dozen specimens of "Arab" glass [23] preserved in Japan in the Shōsō-in at Nara. This houses the property of the Emperor Shōmu, dedicated after his death by his pious queen Kōmio (A. D. 755) to the Todaiji monastery, to which in his lifetime he had been devoted.

So much for glass vessels that were certainly imported, though whether by the transcontinental land route or by sea we cannot say. We can, however, affirm with confidence that glass beads made in the Roman Orient (including Egypt) were traded eastward along the land route. Our evidence for this is twofold: (1) The discovery by Stein in Chinese Turkestan in the neighborhood of the trade route of beads of western origin, as well as of other objects of glass or frit of western origin; (2) the recognition by Mr. Beck and myself of "Mediterranean" eye-beads, of a type common in Egypt, among a large number of minor glass objects collected by Bishop White at Lo-yang (the capital of China during the later part of the Chow dynasty). These may perhaps be dated to the middle of the third century B. C., though Bishop White is inclined to place them two and a half centuries earlier.

The Coptic (Egyptian) gilt beads discovered by Stein come from the Loulan and Niya sites in the Tarim desert, which were abandoned not later than the third and fourth centuries A. D.[24] On the other hand, the Lo-yang beads recognized by Mr. Beck and myself as being Egyptian in origin are of an earlier type, which may be put down to any time within the last half of the last millennium B. C. The site where they were found in China is generally dated to about 250 B. C., which agrees well with their Mediterranean date. The body of these beads is of pale green-blue glass—translucent rather than transparent—with inlaid "eyes" having a deep blue center surrounded by concentric white, brown, and white rings. Not only is there the strongest resemblance, amounting almost to identity, but Dr. Ritchie reports as the result of spectrographic analysis that the specimens "were qualitatively and quantitatively practically identical in composition."

Beads of approximately the same date have also been found, which are not of glass but which copy the Egyptian glass beads to which I

---

[22] I have not included in my examples of early western glass a vase in the Royal Ontario Museum, Toronto, covered with lacquer or some similar substance, and decorated with Amazon heads, as this has not yet been adequately studied. Some account will be found in The Burlington Magazine, 1922, pp. 225–7.

[23] Five of these specimens, figured in vol. 7 (pl. 1–5) of the Shōsō-in Catalogue, may be considered to have been made in Mesopotamia, Persia, or possibly Alexandria and be dated to about A. D. 700. I take this opportunity of thanking Messrs. W. A. H. King and R. Hinks of the British Museum for information concerning the provenance of these early pieces of western glass.

Besides these there are numerous smaller pieces of glass in the Shōsō-in. I have not seen them myself, but owe my knowledge of them to Prof. Jiro Harada, whom I take this opportunity of thanking for his assistance. So numerous are these specimens that it seems unlikely that any considerable number are of western origin. They include 200 glass tips (blue, brown, yellow, and green) for the rods (*jiku*) on which are rolled sutra scripts, and about 62,500 glass beads, while many glass beads of different colors help to compose the headdresses worn by the Emperor Shōmu and his consort. There are also pieces of bead work and lumps of unworked glass.

[24] It must not be thought that Stein's discoveries of Egyptian beads were limited to a particular type of Coptic bead. His finds include many other specimens of Roman-Egyptian type.

have just referred. Presumably these were made for the poorer folk who could not afford anything so expensive as glass, which was certainly of high value in China. They have a composite core, and are covered with a bluish glaze, the "eyes" being produced by local heaping up of brown and white glazes to give the desired effect.

It has been generally accepted on literary evidence that glass was not made in China until the fifth century A. D. Hirth quotes an historical work, the Pei-shih, to the effect that in the reign of the Wei Emperor T'ai Wu (A. D. 424–52) traders from the land of the Ta Yüeh-chih (Bactria) came to his capital [in what is now Shansi], stating that by melting together certain minerals they could produce glass of any color. They were told to find the required material in the neighboring hills, and did this so successfully that the glass they produced was considered superior to that brought from the West. An older work, the Wei Annals, states that the foreigners came not from Ta Yüeh-chih but from Tien Chu-kuo, i. e., India.[25] Stein refers with approval to the above account in connection with his discoveries at Loulan,[26] nor does Hudson dissent,[27] but the facts given below indicate that glass was made in China at least as early as the third century B. C., if not earlier. This is but another example of what has often happened before, namely, a belief accepted on literary evidence has to give way to the findings of archeology. Nor do I base my conclusions solely on the specimens that I have handled or that have been analyzed, for much corroborative evidence will be found in the specimens described and figured by Bishop White in his volume, Tombs of Old Lo-yang.

The import of vessels of such fragile material as glass seems proof positive of the high value attached to this substance in China, and this view is supported by a number of glass objects of minor importance which have come to light in the last few years. Many of these are of Chinese manufacture, as is indicated by the presence in the glass of the element barium in substantial amount, a remarkable fact, since, so far as I can discover, barium, except in traces, is not known to occur in Western or Near Eastern glass, ancient or modern, until about 1884, when, as Mr. Beck informs me, it was purposely introduced as a constituent of some of the new glasses with high refractive index and low dispersion put on the market by Messrs. Schott of Jena.[28]

The beads I shall discuss immediately; other glass objects of interest are the ear ornaments (sometimes called capstan beads) and the ceremonial disks (imitating jade) called pi, placed under the pelvis

[25] Hirth, Chinesische Studien, p. 65, München u. Leipzig, 1890.

[26] Serindia, p. 393.

[27] Europe and China, p. 96.

[28] Analyses of two early beads containing barium will be found in a note contributed by Mr. Beck and myself to Nature, vol. 33, p. 982, 1934. One bead contained sufficient barium to give barium oxide 19.2 percent.

of a corpse, which with glass cross-pieces of swords are known from the graves of those who—as we may infer—could not afford jade.

These beads, containing a high percentage of barium, together with a number of glass plaques, constitute a group of objects of Han or late Chou date, both beads and plaques being sometimes inlaid in bronze or silver. They all have in common the interesting feature that the glass body is inlaid with a number of small white rings, producing eyelets, with a white outline and colored center. Often, but by no means invariably, the white inlay is crescentic rather than circular, producing in the "eyelets" a peculiar revolving effect. In the majority of the beads the eyelets are collected into small groups surrounded by an inlaid circle of white glass, which gives an extremely handsome appearance against the generally dark blue or greenish blue of the glass constituting the body of the bead. These

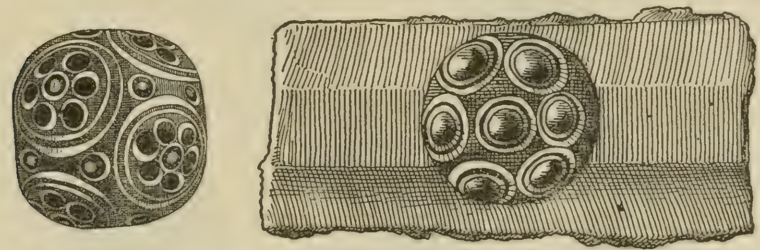


FIGURE 4.—Bead (1/1) and plaque (c. 1/1) of barium glass of Han or pre-Han period.

beads are of high specific gravity, and spectrographic analysis of a number of beads and one plaque, all conforming more or less rigidly to the type described, showed that they all contained barium.

Other pieces of glass, also of supposed Han date, do not contain barium, indicating the existence of more than one center of glass-making in northern China in early times.[29]

Let us now consider the origin of the pattern on these beautiful beads of barium-containing glass. The resemblance of many of the Lo-yang beads to certain beads of diverse and sometimes unknown origin in the Beck collection, as well as to some of definitely known European provenance in various museums, immediately suggests that the prototypes of the ornament of the Lo-yang beads are to be found in the West; and since, where their provenance is known, the majority of the European beads that I suppose to be the prototypes of the Chinese are recognized by archeologists as belonging to the Late Iron Age (though a few may date to the end of the Early Iron Age), we have a date for their spread eastward which accords singularly well

[29] Prof. C. G. Cullis, whom I consulted with regard to the presence of barium ores in China, writes that he knows of no record of "straight" barium deposits in China, but that there are lead-zinc deposits and mines in plenty and that it is from such that he would expect the barium in the glass to be derived. Actually barium and lead are associated in a number of beads, etc., examined by Dr. Ritchie.

with the date of the Lo-yang beads. In fact it would be unreasonable not to admit the high probability that the Chinese beads are imitations, though not slavish imitations, of the European. Figure 5 shows a number of Chinese beads of the Lo-yang type which I have been discussing, and also sketches of two of the presumed European prototypes.

I have, perhaps, devoted overmuch space to glass, but no doubt many objects of beauty and rarity reached the Far East, either directly by caravan or ship or indirectly, passing from hand to hand, being copied and perhaps modified in form in the process of transmission. The bull-headed rhyton is a case in point. I have discussed this

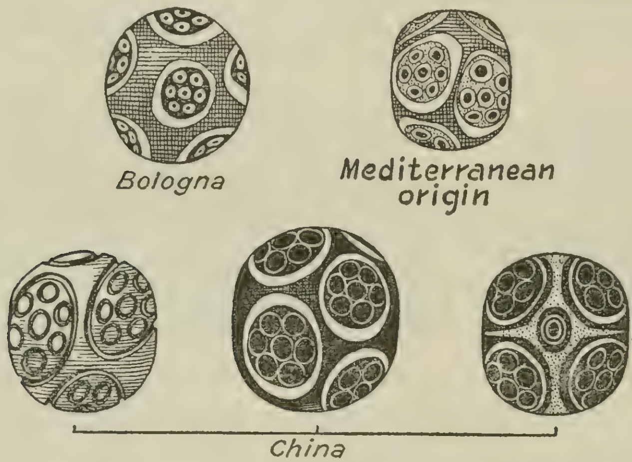


FIGURE 5.—Chinese beads of Han or pre-Han date, with prototypes of "Mediterranean" origin.

elsewhere,[30] so that all I need say here is that there is so close a resemblance between classical, Seleucid or Parthian, and ancient Chinese examples that there can be no doubt that the rhytons of the Near and Far East have a common western origin.

So far I have in the main dealt with events of the Han (206 B. C.—A. D. 220) and the centuries immediately before and after that period. The maximum importance of the silk route, as tapping Central Asia and bringing together the Hellenic and Chinese worlds, was, however, during the T'ang period (A. D. 618–907) to which in the main belong the treasures of the Shōsō-in. Nevertheless "Romans" and Chinese never came into actual contact, owing to the skillful policy of the Parthians, who were determined not to lose their enormous profits as middlemen in the silk trade. Hudson quotes a passage from the Han Annals which, as he says, shows considerable insight:

[30] In Essays presented to Dr. R. R. Marett on his seventieth birthday, Oxford, 1936.

The kings of Ta Ts'in [the Roman Orient] always desired to send embassies to China, but the Parthians wished to carry on trade with Ta Ts'in in Chinese silks and therefore cut them off from communication.[31]

The T'ang world, though no larger, was far better known and more easily traveled than that of any earlier period. We must picture a time when artistic influences from the Hellenic, Indian, and Iranian worlds were pouring into the T'ang capital, Ch'ang-an, frequented by members of the most diverse peoples: pedlars and grooms from Central Asia, "Greeks," Arabs, Persians, Japanese; Hindoos and Jungle men from India (the last presumably in charge of elephants). This list might be extended; it is no effort of the imagination, for at this period there was little Chinese exclusiveness. The T'ang was perhaps the age at which plastic art reached its apogee; it was also a time of great wealth and refinement, in which tomb furniture kept all its old importance, and since many of the foreigners were servants, or in one form or another ministered to the luxury of the wealthier Chinese, there has been opened to us within the last quarter of a century [32] a gallery of plastic portraits excellent in fidelity and often of great beauty, which show us not only the Chinese of that day but also the many foreigners within their gates. Some even exhibit a touch of caricature—the Armenoid (so-called Jewish) nose seems to have been a source of amusement even in T'ang China (pl. 3, fig. 1).

Nor were these foreigners only servants; we know of monks and warriors, the latter bearing treasure, come from afar to worship the Buddha. At Chotcho, a Turfan site, there have been discovered religious frescoes, paintings on stucco covering the walls of cave temples, of the same class (though differing in style) as those exhibited in the Oriental Gallery of the British Museum. The most imposing of those discovered at Chotcho have been published by von Le Coq,[33] and among the paintings of monks and adorers of the Buddha are represented types that clearly do not belong to the Mongol race. Whether these are in any instance actual portrait studies it is impossible to say; I have the impression that they are best regarded as generalized abstractions, in which those features considered to be distinctive of each type are emphasized.

Other evidence of the reciprocal influence of West and East is provided by the frequency of classical designs on Chinese ceramics and by the export westward of Chinese porcelain, which for centuries affected the pot fabrics of the Near East. Western influence is well illustrated by the vase in the Royal Ontario Museum, Toronto, repro-

[31] Hudson, op. cit., p. 84.

[32] T'ang grave figures, if known to Chinese dealers before this date, were not regarded as of any worth; they were not collected by the Chinese and did not reach western collections. It was only when, in the course of building railways in northern China, grave mounds were disturbed without disaster to the violators that grave-goods began to be collected and shipped westward in quantity. There are still Chinese collectors who will have nothing to do with these figures, fearing the results.

[33] Chotcho, Berlin, 1913.

duced in figure 6. This typically T'ang piece bears in relief a dancing figure of classical type, as well as foliate ornament obviously derived from a classical design. Of the export of T'ang porcelain to the West, abundant evidence is provided by the excavations at Samarra (some 70 miles above Baghdad), where numerous examples of Chinese stoneware and porcelain have been excavated under conditions that leave no doubt as to their date, namely the ninth century and for the most part the middle of that century.[34] It is worth noting that many of the sherds of local ware (pottery) imitate imported Chinese pieces, and—to go beyond our period—that such imitations continue in the Near East for several centuries, so that the mounds of Fostat (Old Cairo) abound not only with fragments of early Ming celadons but also with local imitations in faience.

FIGURE 6.—T'ang ewer with classical figure, Royal Ontario Museum, Toronto.

In this connection it is well to emphasize how much more the Chinese of the T'ang period knew of the western world than the western world knew of China. Full accounts of Fu Lin (Byzantium), and of the Arabs and their Prophet have come down to us in Chinese writings. It is not surprising that the Chinese were well informed concerning Islam, for the Emperor T'ai Tsung took into his service the son of the last king of Persia after the Muhammadan conquest of that country. There is an excellent account of Byzantium, obviously the work of a Chinese traveler. He even mentions the mechanical devices that were so much in favor in the eastern Roman capital.

Fu Lin is the ancient Ta Tsin. It is situated on the Western Sea. To the southeast it borders Persia, to the northeast is the territory of the western Turks. The land is very populous and there are many towns. The walls of the capital are of dressed stone, and more than 100,000 families reside in the city. There is a gate 200 feet high, entirely covered with bronze [the Golden Gate]. In the imperial palace there is a human figure of gold which marks the hours by striking bells. The buildings are decorated with glass and crystal, gold, ivory and rare woods. The roofs are made of cement, and are flat. In the heat of summer machines worked by water power carry up water to the roof, which is used to refresh the air by falling in showers in front of the windows.

---

[34] Sarre, F., Die Keramik von Samarra, being vol. 2 of Die Ausgrabungen von Samarra, pp. 54-62, 101, Berlin, 1925, and plates 23-29. Samarra was founded in A. D. 836 and apparently abandoned in 883.

Twelve ministers assist the King in the government. When the King leaves his palace he is attended by a man carrying a bag, into which any person is free to drop petitions. The men wear their hair cut short and are clothed in embroidered robes which leave the right arm bare. The women wear their hair in the form of a crown. The people of Fu Lin esteem wealth, and they are fond of wine and sweetmeats. On every seventh day [the Christian Sunday] no work is done.

From this country come byssus, coral, asbestos, and many other curious products. They have very skilful conjurors who can spit fire from their mouths, pour water out of their hands, and drop pearls from their feet. Also they have skilful physicians who cure certain diseases by extracting worms from the head.[35]

Let me now return to the caravan route that kept the T'ang capital in touch with the West. Besides objects of rarity and value that passed in bulk or from hand to hand along the highway between the Near and Far East, there were those far more important imponderabilia—religion and story. It is not my purpose to discuss the former, but I must mention a piece of painted wood, discovered by Stein at Dandan Uliq in the Takla Makan desert to the east of Khotan and now in the British Museum, which shows the astounding mixture in the religious art of old Khotan. On both sides Bodhisattvas are painted. That on the obverse is a three-headed deity in full Indian style; the figure on the reverse (pl. 3, fig. 2) affords the most striking contrast, presenting, in spite of its four arms, secular Persian treatment in style and accessories.

The clue to the significance of these two paintings was discovered by Stein many years later when examining the mural paintings of a ruin in southeastern Persia, dating to about the seventh century A. D. The Persian bodhisattva represents Rustam, the hero of the Persian national epic, and the three-headed figure is a non-Persian rendering of one of the demonic adversaries conquered by Rustam and forced into submission to his king.[36] Here, then, is a striking absorption of Iranian iconography into the Buddhism of the Far East.

Passing to story, Laufer has shown that the legend of the Diamond Valley reached China from the west. It must be remembered that in the earlier periods the number of gem-stones known to the Chinese was exceedingly limited, while the cut jewel with its qualities of luster and sparkle did not yet exist, so that the beautiful stones which reached the Far East in small quantities from the Hellenistic Roman Orient must have created a profound impression. Laufer points out that the oldest version of the western legend is contained in the writings of Epiphanius, Bishop of Constantia in Cyprus (c. 315–403):

In his discourse on the 12 jewels forming the breastplate of the High Priest of Jerusalem, the following tale is narrated of the hyacinth. The theater of action is a deep valley in a desert of great Scythia, entirely surrounded by rocky moun-

[35] Fitzgerald, op. cit., pp. 323–4. To a question as to how closely this account could be dated, Mr. Fitzgerald expressed the opinion that, while accurate dating was impossible, it could probably be attributed to the seventh or eighth century.

[36] Stein, On Central Asian Tracks, pp. 64–65, 1933.

114728—39——37

tains rising straight like walls; so that from their summits the bottom of the valley is not visible, but only a sullen mist-like chaos. The men despatched there in search of those stones by the kings, who reside in the neighborhood, slay sheep, strip them of their skins, and fling them from the rocks into the immense chaos of the valley. The stones then adhere to the flesh of the sheep. The eagles that loiter on the cliffs above scent the flesh, pounce down upon it in the valley, carry the carcasses off to devour them, and thus the stones remain on the top of the mountains. The convicts condemned to gather the stones go to the spots where the flesh of the sheep has been carried away by the eagles, find and take the stones.[37]

The Chinese text contained in the Liang ssŭ kung chi (Memoirs of the four Worthies of the Liang dynasty) gives the following account:

In the period T'ien-kien (502–520) of the Liang dynasty, Prince Kie of Shu (Sze-ch'uan) visited the Emperor Wu, when he told his story: "In the west, arriving at the Mediterranean, there is in the sea an island of 200 square miles (*li*). On this island is a large forest abundant in trees with precious stones, and inhabited by over 10,000 families. * * * In a northwesterly direction from the island is a ravine hollowed out like a bowl, more than a thousand feet deep. They throw flesh into this valley. Birds take it up in their beaks, whereupon they drop the precious stones." [38]

This account, for all its brevity, is immediately intelligible in the light of the western legend, with which it coincides in its essentials—the deep valley into which raw flesh is thrown as bait for the birds, who with it carry the stones into accessible positions. Laufer's conclusions are then justified, the Liang version is directly traceable to that of Epiphanius, and was transmitted to China from Fu-lin, part of the Roman Empire.[39]

So, too, Hellenistic and Chinese folklore mingle in the ideas transmitted from west to east, distorted, and reflected back again, concerning asbestos and the salamander. Strabo and Dioscorides both knew the plain facts about asbestos, its mineral origin and its fire-resisting property; so did the Chinese of Han times. It is only later that western beliefs concerning the salamander and the phoenix being born of fire or uninjured by fire are confused with asbestos cloth, the latter being further confounded with the real bark cloth of Malaya, which the Chinese knew from their travels in Java and Cambodia, so that finally the incombustible cloth really obtained from the west is either the plumage or pelt of western fire-loving mythical birds or beasts.

These examples show the diffusion and penetrative power—if I may use the phrase—of ideas and beliefs of a curious and recondite character. The examples I have given have nothing to do with the fundamental needs or desires of mankind, though no doubt the won-

[37] Laufer, Berthold, The diamond, a study in Chinese and Hellenistic folk-lore, Field Museum of Natural History, Publication 184, vol. 15, No. 1, p. 9, Chicago, 1915.

[38] Laufer, op. cit., pp. 6–7.

[39] Laufer, op. cit., p. 10.

ders of far off lands have always had a strong appeal. How much stronger will this appeal be when the ideas transmitted have to do with the most deep-seated of all longings, the defeat of old age and death.

We may, I think, regard it as a priori unlikely that the Elixir Vitae was of Near Eastern origin, since there is no mention of anything of the sort in the innumerable Egyptian texts that have come down to us; nor is any such substance recorded in the cuneiform texts of the Sumerians or Assyrians.[40] On the other hand, there is the general belief that alchemy (the transmutation of metals) arose among Alexandrine Greeks in the early centuries of our era, later reaching central Europe via the Arabs. In Alexandria transmutation had a philosophical basis; moreover the earliest Greek alchemical writings abound in references to Near Eastern authorities and traditions,[41] but although the Leyden papyrus of the end of the third century, from Thebes, indicates how jewellers may imitate gold and silver, there is no reference to the Elixir, and in the West it was only later that the substance for transmuting metals was considered to have the property of prolonging life indefinitely.

The earliest alchemical writers who have left literary remains lived at a period extending from the third to the fifth centuries,[42] when Alexandria was still a great commercial metropolis. A large portion of the Chinese trade reached Alexandria; and just as legends concerning the Valley of Diamonds and asbestos were transmitted to the Far East, so Far Eastern ideas concerning the Elixir might well be discussed in this western city of philosophers. In China such ideas were already well developed centuries before the beginning of the Christian era, for Ch'in Shih Huang Ti (249–210 B. C.), the "First Emperor" is recorded as having occupied much of his later life in the search for immortality, to be gained by means of a magic drug believed to exist in the three Isles of the Immortals in the Eastern Sea. These islands, P'êng-lai and its fellows, were not so very remote from the home of mankind, and they had been seen by many though it was impossible to land. Having come under the influence of two celebrated magicians the Emperor organized an elaborate expedition in search of the islands. The expedition did not return, but this failure did not daunt the Emperor, and to the end of his days he sought to discover some means of contact with the immortals and to gain access to their elixir.

It should be pointed out that long before this, jade had been regarded as prolonging life and preserving the tissues from corruption—as indi-

[40] The large collection of magical texts, coming down to Coptic times, published by Francois Lexa under the title La Magie dans l'Égypte antique, Paris, 1925, contains no text referring either to the Elixir or to the transmutation of metals. With regard to Mesopotamia, my statement is made on the authority of Dr. Campbell Thompson.

[41] Encyclopaedia Britannica, 14th ed., 1929, s. v. ALCHEMY.

[42] Stillman, John M., The story of early chemistry, p. 150, New York, 1924.

cated by its use in the burials of the great.[43] So too, gold, and especially gold obtained by transmutation, could be used to assure immortality:

[The wizard Li] Shao-chün said to the Emperor [Wu Ti of Han]: "Sacrifice to the stove [*tsao*] and you will be able to summon 'things' [*i. e.*, spirits]. Summon spirits and you will be able to change cinnabar powder into yellow gold. With this yellow gold you may make vessels to eat and drink out of. You will then increase your span of life. Having increased your span of life, you will be able to see the *hsien* of P'ĕng-lai that is in the midst of the sea. Then you may perform the sacrifices *feng* and *shan* and escape death".[43 44]

The Elixir Vitae is also mentioned in another important work, the Ts'an T'ung Ch'i, written under the pseudonym Wei Po-yang in the second century A. D. Waley thinks it likely that the text may have been doctored to give an alchemical interest later, i. e., in the fourth century. This view does not imply any considerable rearrangement, for only one of the 90 sections into which the text is arranged deals specifically with the Elixir, and this in the most definite manner:

Gold by nature does not rot or decay;
Therefore it is of all things most precious.
When the artist [i. e., alchemist] includes it in his diet
The duration of his life becomes everlasting
* * * * * * *
When the golden powder enters the five entrails,
A fog is dispelled, like rain-clouds scattered by wind.
Fragrant exhalations pervade the four limbs;
The countenance beams with well-being and joy.
Hairs that were white all turn to black;
Teeth that had fallen grow in their former place.
The old dotard is again a lusty youth;
The decripit crone is again a young girl.[45]

We cannot say how early the belief in the life-giving virtue of gold may have arisen; the first text given above, though attributed to the first century B. C., may be a hundred years or more later,[46] but it is obvious that the belief must have existed at an earlier date than the text. Linking this to what we know of the Elixir in the West, it seems reasonable to infer that the belief originated in China,[47] for these texts

[43] Space is lacking to describe the virtues of jade: though the product of the earth, it is at the same time the essence of Heaven, perfected under high spiritual influence (Laufer, Jade, p. 148, 1912). Appropriate emblems of jade were placed upon or within the orifices of the body, e. g., the cicada in the mouth, and ceremonial objects of jade were placed within the coffin in contact with the body. Naturally it was only the rich whose grave-furnishings were of jade; I have already alluded to the glass *pi* (p. 558) of the less well-to-do.

[44] Waley, A., Notes on Chinese alchemy, Bull. School of Oriental Studies, vol. 6, p. 2, 1930–2. Chinese words have been omitted and only their transliteration given.

[45] Waley, op. cit., p. 11. It might have been expected that jade rather than gold would have been cited in the texts quoted. Mr. Waley has suggested to me that the admiration for gold was adopted from the northern nomads at the time when their costume and military tactics were taken over by the Chinese.

[46] Waley, op. cit., p. 3.

[47] In arguing that the Elixir Vitae as known to the western world since the early centuries of our era originated in China, I do not ignore the view put forward by the late Prof. Sir Grafton Elliot Smith and Dr. W. J. Perry that all "life givers" had their origin in the beliefs of Ancient Egypt, which spread across Eurasia at a comparatively early date. I would, however, point out that even if this view be held the diffusion westwards of a conception which was flourishing in the Far East in the latter half of the first millennium B. C. can still be accepted.

that I have cited, coupled with what we know of the accredited properties of jade, seem to prove the existence of a strongly held belief in the Elixir Vitae in the Far East at a time when there is no evidence for the existence of this belief in Europe. Moreover it seems probable that more evidence in favor of this view might be derived from a new examination of Chinese sources, for Laufer's great work on jade was published in 1912.

The last matters to which I shall refer are those two great gifts of China to the West, paper and printing, the latter for practical purposes impossible without the former. Up to the end of the Chou dynasty writing was done with a bamboo pen upon slips of bamboo or wood. Then came the writing brush of hair. This is the traditional Chinese belief, but the modern view as set forth by Yetts is that brush calligraphy existed in the Shang-Yin period, than which we have no earlier relics. Referring to two Shang-Yin inscriptions, which he reproduces, he denies that the "spontaneity and modulation of their line" makes possible any other agency. Certain pictograms in the archaic script are adduced, which clearly represent a hand holding a brush. These come from a Honan bone and a Shang-Yin bronze.[48] Moreover, recent excavations near An-yang have brought to light three fragments of bone, used by Shang-Yin diviners, on which there are remains of writing done with ink and brush.[49] Paper, or near-paper, was invented about the end of the first century A. D., traditionally in the year 105. Rag paper dating from the middle of the second century was discovered by Stein at Tun Huang in the form of eight letters on paper (together with letters on silk and wood). Discoveries at Turfan date to the end of the fourth century. These, together with later documents from Turkestan, show that the paper was manufactured from both raw fiber and worked-up material, e. g., the remains of old textiles and fishing nets, a discovery indicating that it was not the Muslims of Samarkand who, as commonly held, originated rag paper:

> Rag paper, supposed till 1885 to have been invented in Europe in the fifteenth century, supposed till 1911 to have been invented by the Arabs of Samarkand in the eighth century, was carried back to the Chinese of the second century, and the Chinese record, stating that rag paper was invented in China at the beginning of the second century, was confirmed.[50]

Gradually the Chinese improved the composition and face of their papers, so that it was a perfected invention that passed from the Chinese to the Arabic world. Thence it reached Baghdad in the

---

[48] The George Eumorfopoulos Collection, Catalogue of the Chinese and Corean Bronzes, etc., vol. 1, see especially pp. 15–17, London, 1929.

[49] Tung Tso-pin in Studies presented to Ts'ai Yüan P'ei on his Sixty-fifth Birthday, pp. 417, 418, fig. 7, Pei-p'ing, 1933.

[50] Carter, Thomas Francis, The invention of printing in China and its spread westward, p. 5, New York, 1931. To this work I gratefully acknowledge my indebtedness for this short account of early paper and printing.

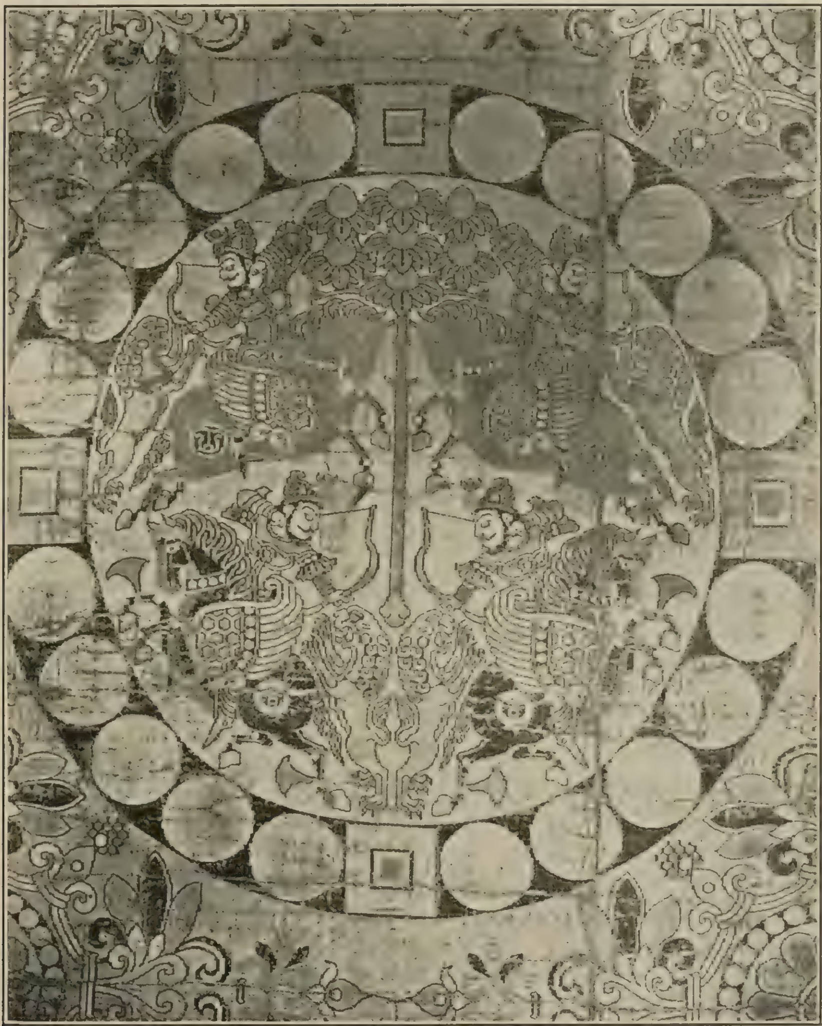
eighth century, Egypt soon after, whence via Morocco (c. 1100) to Spain, and so to Central Europe, having also reached Italy via Libya and Sicily.

Without considering the part that seal-stones and rubbings from graved stones (lithography in its simplest form) may have played in the evolution of printing, let me say that there may be some doubt as to the accuracy of a reference to printing in China at the end of the sixth century, and emphasize the fact that the earliest datable block-print extant is of A. D. 770 and comes from Japan. Block-printing must, however, have been practised in China sufficiently long before this for it to have attained such considerable development in Japan, since the relics of A. D. 770 (for a number have been preserved) are of the series of one million charms ordered by the Empress Shotoku. Examples of these preserved in the Horiuji monastery at Nara in Japan, in the British Museum, and in the museum at Leipzig, show that the strips of paper used are about 18 inches long by 2 wide, each bearing 30 columns of 5 characters each.[51]

Japan produced no books at this time, or if she did they have not come down to us. The earliest printed book (i. e., scroll) that can be dated with certainty is Chinese and was produced in May 868—no primitive piece of printing like the Japanese charms but a superb version of one of the holiest of Buddhist texts, the Diamond Sutra, though there is reason to believe that a copy of the Kuan Yin Sutra in the British Museum may be even earlier, of 8th century date (pl. 4).

The T'ang dynasty came to its end within a hundred years of the printing of the Diamond Sutra, and it is not my purpose to attempt to carry my sketch of the contacts of West and East beyond the years of that dynasty. A kindly critic has suggested that I should conclude with a summary. This seems unnecessary, for I have done little more than touch on each of the subjects that I have put before you. I may, however, express the opinion that early contacts between Europe and the Far East will, as knowledge advances, prove to have been far more numerous than has hitherto been generally accepted.

[51] Carter op. cit., p. 36.



HUNTER SILK, HORIUJI MONASTERY, NARA.

1. GLASS BOWL, SILLA ROYAL TOMBS, KOREA.

2. GLASS BOWL FROM HONAN, NORTHERN CHINA.

1. ARMENOID FIGURE, T'ANG PERIOD.

2. PAINTED WOODEN PANEL REPRESENTING BODHISATTVA (STEIN, ANCIENT KHOTAN), BRITISH MUSEUM.

PRINT FROM WOODEN BLOCK DATED 868, PART OF DIAMOND SUTRA SCROLL, BRITISH MUSEUM.

AN ANCIENT CHINESE CAPITAL
EARTHWORKS AT OLD CH'ANG-AN[1]

By Carl Whiting Bishop
Freer Gallery of Art, Washington

[With four plates]

Not least in interest among subjects of archeological study is that which has to do with the types of fortification constructed by organized communities in the past. These, once the habit of town-dwelling had become fixed, seem to have tended to fall into two major classes: the arx, acropolis, or citadel, one of whose functions it was to provide a temporary refuge in emergency; and the enceinte or city-wall proper, designed to afford permanent protection to the group living within it. Sometimes the two forms occur in combination; more often, singly.

The first type we frequently, though by no means always, find situated on a height; the acropolis of Athens and the Capitoline Hill at Rome are familiar examples. The second class, on the other hand, seems to have developed more especially in those alluvial plains on which sprang up the great river-valley civilizations of the ancient world. To it belong the tremendous earthworks constructed slightly over 2,000 years ago about the city of Ch'ang-an (meaning "Long Peace"; possibly Ptolemy's "Sera Metropolis"[2]), the capital of the then recently established Chinese empire.

It was in 221 B. C.—the year, it will be recalled, when the Carthaginian troops in Spain proclaimed Hannibal their commander-in-chief—that at the opposite end of the Old World the great conqueror Ch'in Shih Huang-ti[3] set up, on the ruins of a very ancient and separatist Chinese feudalism, a centralized and bureaucratic empire which in many details of its organization strikingly recalls the one established some three centuries earlier in western Asia by Darius the Great.

[1] The following account contains material included in a report, now in course of preparation, dealing with the investigations conducted in China during the period 1923–1934 by the Freer Gallery of Art, Washington, D. C. Reprinted by permission from Antiquity, vol. 12, No. 45, March 1938.

[2] On this identification, see e. g., Grousset, René, Histoire de l'Extrême-Orient, vol. 1, p. 212 and note 5, Paris, 1929.

[3] This name, or rather title, means literally "First Emperor of the Ch'in (Dynasty)"; he is mentioned, in another connection, in Antiquity, vol. 11, p. 27, March 1937.

Shih Huang-ti's dynasty, the Ch'in [4] (or Ts'in, as the name is sometimes spelled in English), fell a very few years after his death. There ensued a brief period of civil war and general turmoil. Out of this there emerged as victor a low-born but nevertheless very able adventurer who thereupon founded the Former or Western Han Dynasty (206 B. C.–A. D. 7).[5] This was the man usually known in later history as Han Kao-tzŭ (his posthumous title); he played a part comparable to that of Octavius not quite two centures later in putting an end to a period of civil strife and setting up a stable government. He at first thought of fixing the capital of his newly won dominions a short distance south of the Yellow River, in what is today the province of Honan. Ultimately, however, he established his permanent official residence some 200 miles farther to the west, in central Shensi province. The city which he thus founded soon became one of the greatest of its day, anywhere in the world. Ch'ang-an during the period of its prosperity may have been rivalled in population and perhaps in extent by certain cities of the Near East and of northern India; but Europe certainly had nothing as yet even remotely comparable to it.

Then as always, however, Chinese architecture was essentially one of wood and terre pisé. Hence the ancient capital of the Hans has left us, above ground at least, but few remains of itself. Of these the most notable are portions of its great rampart of solidly tamped earth, and what is said to have been the foundation-mound of the principal building in the imperial palace-enclosure—the celebrated Wei Yang Kung, of whose almost fabulous splendor and magnificence many tales are told.

The site of the ancient city lies 4 or 5 miles northwest of Hsi-an Fu (sometimes spelled "Sianfu" in English), the capital of the province of Shensi, and a little south of the historic Wei, a western affluent of the Yellow River. The country hereabout is an intensively cultivated alluvial plain which rises into hills some distance to the south.

The morning was misty, the visibility poor; but as we approached the site we began to see ahead of us a lofty and now shapeless mound, obviously artificial in origin. This stood, we found, at the southeastern corner of the ancient city. Closer examination showed that it was composed of successive layers of terre pisé, rammed very hard and averaging about 4 inches in thickness.[6]

[4] From this word almost certainly came our name "China." Those who deny this (usually on the ground that the name "China" antedates the founding of the Ch'in empire) forget that the state of Ch'in was established several centuries earlier, and long before Shih Huang-ti's time had already annexed the eastern termini of both the great land-routes linking the Far East with the Occident, the one by way of Central Asia, the other through Farther India.

[5] The Han Dynasty, it should be remarked, was the first Chinese ruling house to spring from the ranks of the common people. The founders of all the earlier ones had belonged to the turbulent, hard-drinking, chariot-fighting feudal nobility, the possessors of the Chinese Bronze Age civilization (in regard to the latter point cf. Antiquity, vol. 7, p. 404, December 1933).

[6] Recent excavations at the two opposite ends of the Asiatic continent have shown that the use of terre pisé construction dates back, in China at least to the second millenium B. C. and in the Near East considerably earlier still.

The present height of the mound we estimated at around 50 feet. That it had once been surmounted by a large building of some sort, presumably a wooden castle, was indicated by the occurrence, both on its sides and in the loose earth at its foot, of large gray unglazed roofing-tiles of the kind used in China during the Han period. Lying all about was much broken pottery, in part likewise of Han date. On top of the mound was a ruinous square beacon-tower of gray burnt brick; this structure, of a type still to be seen all over northern China and formerly used in the transmission of smoke or fire signals, was probably not over 3 or 4 centuries old. From it we could see, stretching away to north and to west, the remains of the ancient city's great ramparts of earth. These, though in some places still quite well preserved, were for the most part much eroded, terraced for cultivation, and here and there almost completely dug away.[7] Their entire perimeter we could not attempt to trace, for want of time. Old Chinese maps suggest, however, that their circuit is somewhere around 15 or 16 miles; they indicate too that the old city was roughly quadrangular in plan.

Part at least of the material composing these ramparts was pretty surely taken from what was now a dry moat or ditch which we saw just outside them. This we found, at the point where we measured it, 160 feet wide, with a present average depth, even though now much silted up, of nearly 10 feet. If it had ever served as a wet moat, the water to fill it must have come from a stream, shown on old Chinese maps but now no longer in evidence, which seems to have flowed into it near the southwestern corner of the city.

Immediately west of the great corner mound just mentioned, there was in the south wall of the ancient city a wide opening through which ascended (see post) the cart road by which we had come out from Hsi-an Fu. This gap provided us with an excellent cross-section of the rampart as well as a convenient opportunity for measuring its profile.

It proved to have been constructed throughout of layers of terre pisé identical with those already mentioned, and was quite without anything in the way of a revetment. Closely similar in their method of construction, except that they are usually provided with outer and sometimes also inner facings of large gray burnt brick laid in lime plaster, are the walls of many existing Chinese cities (pls. 1, 2). Occasionally, as for instance in the "Red Basin" country of the western province of Szechuan, where an easily worked red sandstone is readily procurable, these revetments are of dressed stone laid in regular courses of equal thickness, recalling the opus isodomum of

[7] Such accumulations of earth, on account of their high ammonia content, are much used by the northern Chinese peasantry as fertilizer. Analogous practices are found elsewhere, as for example in the terremare of north Italy and the terpen of west Friesland.

Vitruvius. In general, however, the walls of Chinese cities have always been of earth, in later centuries generally, though not always, faced with brick. Significant of this is the fact that the ideograph for "city-wall" [8] has as its determinative or "radical" the character for "earth." The original Great Wall of China, constructed a few years prior to the founding of Ch'ang-an and just at the time of the Second Punic War, was likewise of earth, as indeed are long portions of it still (cf. pl. 3).

The ancient rampart which we were studying rested directly upon the original surface of the soil, without the interposition of a stone plinth or a damp-course of any kind. Its thickness at the base we found to be 350 feet. Protruding from the western side of the aforementioned gap, near the top of the wall, were remains of what had evidently been a drainage-system of gray unglazed tile; for the region, though in general comparatively dry, experiences torrential summer rains. At the foot of the rampart's outer face, still quite steep (owing to the durability of the terre pisé) even after the lapse of 20 centuries, we found traces of a narrow berm (see fig. 1, drawing of

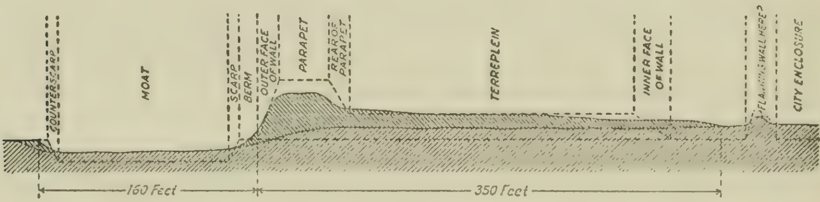


FIGURE 1.—Drawing of profile of rampart, old Ch'ang-an; suggested restoration in broken lines.

cross-section of rampart), now almost worn away. It may originally have been 15 feet wide, possibly even less; in any case barely enough, it seemed, to withstand the thrust of the vast mass of rammed earth above and behind it.

The vertical height of the outer face, above the berm, we found to average 25 feet in its present state. We noticed particularly that there were in the line of the wall none of those rectangular projections or salients, often loosely called "bastions," seen in many of the Chinese city walls built during more recent centuries (see pl. 4). On the contrary, at old Ch'ang-an we saw only the long straight curtain-wall, with no provision, save possibly at the city gates (see post), for the directing of a flank fire against bodies of assailants.

Extending back from the brink of the outer face of the rampart were the remains of a platform or parapet of pisé, once no doubt level but now much cut up by erosion and cultivation. This was 42 feet across at the widest of several points where we measured it; while in places its now very irregular inner edge rose as much as 10 feet above

[8] The same character, pronounced ch'êng, also means "city;" for according to the traditional Chinese way of thinking, the wall is what makes the city.

the terreplein behind it. The latter sloped gradually and on the whole evenly downward to the general level of the area inside the walls; there was no sudden change of profile to indicate where the terreplein had terminated and the inner face of the rampart had begun (cf. fig. 1). That this did not represent the original condition, however, appeared likely, for the following reasons.

We found, in the first place, that this long interior slope was for the most part covered with uncompacted earth, in places to a depth of 4 or 5 feet and obviously washed down from the parapet above. Secondly, at certain points beneath this layer were to be seen portions of what appeared to be a continuous stratum containing Han roofing-tiles, bricks, and potsherds and resting directly upon the tamped earth of the original agger. These facts suggested, first, that the top of the parapet had once been somewhat more than 10 feet higher (see ante) than the terreplein; and, second, that on the latter had once stood buildings, erected presumably on a level, not a sloping, surface. Thus we might reasonably suppose that the rampart as originally constucted had had, in addition to a parapet, a true terreplein and a distinct inner face—the latter doubtless much lower than the outer one and now completely masked by detritus washed down from above.

As already stated, the cart road from Hsi-an Fu entered the ancient city enclosure through a wide gap at the eastern end of the southern wall. This opening, we felt certain for several reasons, indicated the spot where once had stood a city-gate. None of the old Chinese maps of Ch'ang-an appears to show a gate at this spot; nor does it seem very probable that one should have been placed there; for gates do not ordinarily occur at the corners of Chinese city walls. Possibly the gap in question may have been cut through the rampart at some time subsequent to the original building of the wall.

Be that as it may, the track here mounted quite steeply and once inside the enceinte turned abruptly to the left or west. This change in direction brought it parallel to a low rise in the ground directly across the opening and a short distance inside or north of it. Whether this rise represented what had originally been an earthen wall forming part of the defences of the gate, we were unable to determine by inspection alone. But had there been such a wall, its effect would have been to compel an attacking force, once it had broken through the gate, to turn sharply to the left and thus expose its right or unshielded side to an enfilading fire from the defenders.[9]

For some 400 yards or so to the west of the above gap we found the gigantic agger displaying in general much the same profile and dimensions as those just described. Then came a second wide opening,

[9] Shields formed part of the equipment of the Chinese warriors of the time, as shown, for example, on the famous Han "reliefs" (in reality incised drawings on stone slabs) from the province of Shantung and by numerous passages in the surviving historical records.

where, we felt sure, there had formerly stood another gate. Flanking this on either side, on top of the rampart were the badly eroded stumps of two mounds. On these, it appeared likely, had once stood twin gate towers, doubtless of wood; for in the earth about their bases we found embedded numbers of large roofing tiles of the kind already mentioned. Such gate towers seem sometimes at least to have been joined by a covered gallery of wood extending from side to side above the top of the gate proper.

The Chinese gate tower of later centuries, as is well known, has been a single structure built directly over the opening in the city wall, usually in two or three stories, with the upturned roof corners so familiar on Chinese buildings.[10] What appears to have been the older type, with twin towers flanking the gateway, is still, however, to be seen in a few provincial towns.

A road passed through this second gap also. Upon entering the city it turned, like the other, at a right angle toward the west. Here, too, this abrupt change in direction seemed to have been determined by a transverse rise in the ground just inside the opening.

Extending from this second gap directly across the moat to the counterscarp we found what seemed once to have been a causeway, now much broken down. This, as far as we could tell, had not been constructed of terre pisé, but had been merely a strip of the original soil, left untouched when the moat was dug; it thus recalled in a way the "interrupted ditches" found at certain prehistoric sites in the Occident. Over its remains passed the road mentioned in the preceding paragraph. We had noticed nothing suggesting the former existence of a similar causeway at the first gap—perhaps an additional indication that the opening there was made at some later period.

From this point we traced the rampart for some distance farther to the west, and found it growing more and more eroded and worn away, until at length it practically disappeared save for a few uncertain remains. Others, apparently better preserved, we could see far away across the river-plain; but these we had not the time to visit.

Before we leave our discussion of these earthworks, it will perhaps be of interest to touch briefly on the probable reason for their enormous and seemingly unnecessary thickness. For the tremendous additional labor and expense thus incurred can only have been undertaken for the sake of providing against some very real and compelling danger.

During the middle of the first millennium B. C. the arts of war and notably of siege-craft made great progress in China. Particularly was this true in regard to the use of mines. These were employed, then as later, for two purposes: the one, to gain direct access to the interiors of beleaguered towns; the other, to overthrow their ramparts and thus

[10] These upward-curving roof corners were a post-Han development in Chinese architecture. Until long after the beginning of the Christian era, Chinese roofs had straight lines.

effect a practicable breach for a storming party. The latter aim the Chinese military engineers of that day did not achieve with the aid of explosives, then still unknown in China as elsewhere. Instead, they tunneled beneath the earthen city walls and there excavated a large chamber whose ceiling they supported by means of stout timbering; this they then set on fire, thus causing it to give way and allow the section of rampart immediately above it to drop into the cavity.

The earliest mention in Chinese literature of this proceeding, so far as I know, dates back to around the beginning of the fourth century B. C.[11] and the passage would imply that it had already then been known in China for some time, perhaps even as much as a century or two, although scarcely more than that. For prior to around the middle of the first millennium B. C. the methods employed by the Chinese in the capture of walled towns had been chiefly those of surprise, escalade, or blockade. As in the Occident (e. g., at Croton in 510 B. C. and at Mantinea in 385 B. C.), so in China also, rivers were sometimes diverted against city walls and made to undermine them. It seems to have been slightly later (i. e., after the middle of the same millenium) that in both China and the West there came into use the above-described method of breaching walls by mining. It was employed in the latter region, for instance, at the siege of Megalopolis by Polyperchon [12] in 318 B. C. and at that of Abydos by Philip V of Macedon in 200 B. C.

It is only fair to say, however, that the best military opinion in ancient China, such as that of Sun Tzŭ,[13] was in general opposed to the investment of fortified places, preferring rather to bring about their surrender by overcoming the enemy's forces in the field.

In any event, against a rampart so massive and a moat so wide and deep as those which we saw at old Chʻang-an, even the most effective methods of siege-craft known to the ancient Chinese must have been well-nigh powerless. The capital of the Hans, though seated in a wide plain and so owing nothing of its strength to natural position, must have been as nearly impregnable to direct assault as was ancient Babylon.

The space inside the ramparts was, we found, a slightly undulating plain dotted with the mud hamlets of the local peasantry and with clusters of small modern grave mounds shaded by trees; but for by far the greater part under intensive cultivation. As we might expect in a city occupied for so long a period (in all about 200 years) as was old Chʻang-an, the present surface of the site, within the walls, was

[11] Mo-tzu, chap. 14, par. 62.

[12] Formerly miscalled "Polysperchon."

[13] Also called Sun Wu; fl. 4th century B. C. On his writings see Giles, Lionel, Sun Tzŭ on the art of war (trans. from the Chinese, with notes), London, 1910.

on the whole distinctly higher by several feet than was the surrounding country. Accumulations of downwash from the inner slopes of the earthen walls have no doubt been responsible for some of this rise in level; but much—probably most—of it was certainly the direct result of long continued human occupation. Similarly, the level of the area inside the walls of Peking, inhabited continuously for a period roughly three times as long as was Old Chʻang-an, is today in many places from 20 to 30 feet higher than it was originally.

Immediately west of the city proper, and separated from it by the much eroded remains of two parallel earthen walls of no great size which ran north and south about a hundred feet apart, we came upon the old palace-enclosure of the Han emperors. The surface here also was somewhat undulating in character. Some of the slight irregularities in level made us wonder whether they might not conceal the

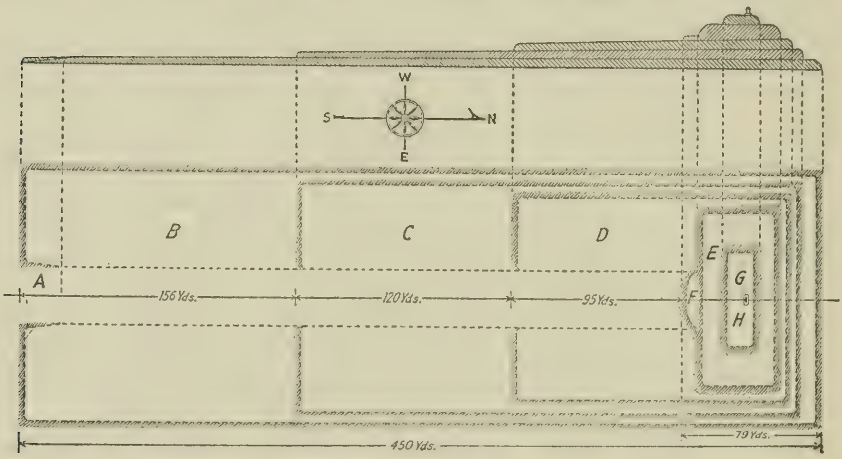


FIGURE 2.—Plan and elevation of Wei Yang Kung Palace foundation-mound, Old Chʻang-an.

remains of ancient buildings; for the records speak of a number of palaces. The ground here, however, just as in the city proper, had been so long and so continuously under the plow that all surface indications had disappeared, except at one point.

Here, some hundreds of yards ahead of us, a little to the south of west, we saw a long mound in several superimposed stages, with its major axis extending due north and south and perhaps coinciding with that of the palace-city itself. This mound, our Chinese companions told us, had been the foundation platform of the principal edifice in the old palace complex, the celebrated Wei Yang Kung already mentioned (for its plan and elevation see fig. 2).

We found the ground-plan of this interesting construction that of a long rectangle, with corners surprisingly well defined considering its age. The total length was 450 yards, its breadth 145 yards, and it

was built in five stages, of which the highest, near the northern end, rose some 50 feet above the surrounding fields. It had been constructed of successive layers of terre pisé like those forming the rampart that we had just been examining, and was now thinly covered with grass save for patches of cultivation here and there, and for a few great stones of which we shall speak in a moment.

Exactly at the center of the southern end of the rectangle we found traces of an approach or gradual ascent of some kind, apparently a ramp (marked A on the accompanying plan, fig. 2), about 100 feet in width east by west. It extended north, sloping gently upward the while, for some 70 feet, to the level of the top of the lowest terrace (B on the plan). The surface of the latter, aside from the ramp, was practically level and extended for 156 yards until it came to the second stage (C), marked by a sharp rise or step of 2 feet. From this point north, a slight upward slope brought us to another abrupt rise of 2 feet marking the beginning of the third terrace (D). The ground thence continued rising gently until, 95 yards still farther north, it reached the edge of the fourth stage (E). This was a steep earthen bank some 10 feet high; from its southern face there projected a somewhat lower platform of earth (F), now much eroded but apparently once rectangular in form; its ends were in exact alignment with the borders of the (unpaved) avenue of approach, which we had been able to trace, intermittently, up to this point.

The mound culminated in a long, narrow terrace (G) about 12 yards wide north and south and extending east by west for some 65 yards; its fairly level top stood about 6 feet higher than the preceding stage. Here, at the apex of the mound, was a commemorative stela encased in brickwork (H), erected in the year 1695 at the behest of the great Manchu emperor commonly called by Europeans K'ang-hsi.

The rearward or northern end of the mound descended to the level of the fields about it in a series of unequal and now much eroded stages—the borders of the successive terraces just described. These, however, projected far less beyond one another here than they did on the south; the total distance from the center of the uppermost stage to the northern edge of the lowest amounted only to some 50 yards, as against about 400 yards in the opposite direction.

Scattered here and there over the surface of the great rectangle were several large water-worn boulders, already mentioned (these I have not indicated on the plan (fig. 2) as we were too straitened for time to determine their positions even approximately). These were not grouped or arranged in any regular order. They rested directly on the tamped earth of the mound at varying heights above ground-level, and could only have reached their present position through human agency. According to the surmise of our Chinese companions, they may have been ornaments in some garden or pleasance within the

ancient palace. It seemed clear at all events that they had not fulfilled any structural purpose.

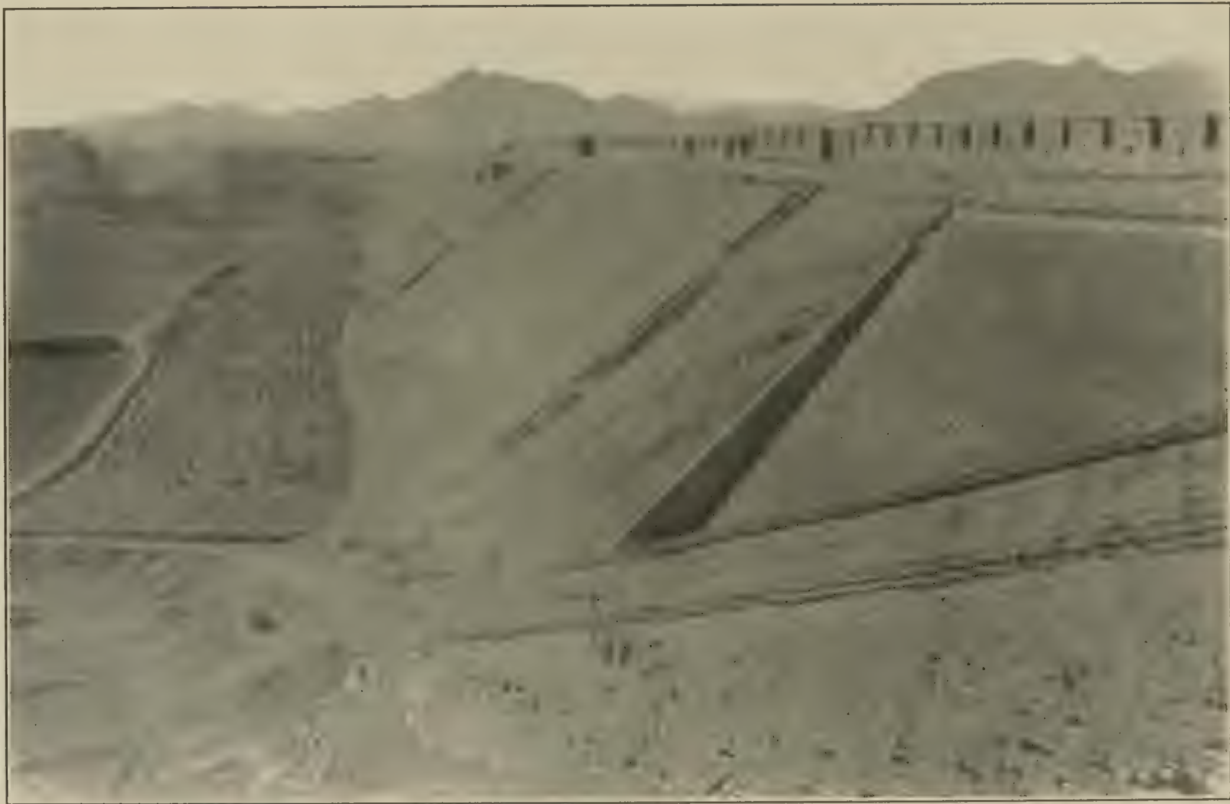
The Wei Yang Kung mound as we saw it, even in its present state of nakedness and desolation, possessed a certain aspect of dignity and proportion and balance. Rising out of a level plain, and covered as it was during Han times by stately buildings (probably with painted or lacquered columns and brightly colored roofs of tile),[14] it must have presented a most inspiring spectacle to all who beheld it—to the native subjects of the Son of Heaven themselves as well as to the visitors from many lands, some of them in the distant West, who we know thronged the capital city of the Hans.

In China the walls of cities have retained their usefulness as in perhaps no other country. An instance of this occurred a few years ago, during a civil war. The attacking force attempted to use poison gas; whereupon their opponents retired inside a walled town, closed its gates, and found themselves quite safe. City walls have been placed in repair (although probably not constructed de novo) in China in very recent times. The study of their development there through so long a period is therefore particularly instructive.

The earthworks at old Ch'ang-an, dating as they do from an epoch when China's Bronze Age had only comparatively recently become one of Iron, are especially worthy of study. During the few hours that we were able to spend there, we saw enough to convince us that systematic and extended excavation would beyond doubt yield results of very great interest. Moreover, the nature of the site was such as to lend itself particularly well to survey by airplane. Vertical air photographs of its varied features would be of especial value and would be almost certain to reveal details which had escaped our notice on the ground.

---

[14] Roofing-tiles of baked clay seem to have come into use in China during the Eastern Chou period (770–255 B. C.). By Han times, from around 200 B. C. onward, those used to cover important buildings had begun to be painted in bright hues. It was not until the epoch of the Six Dynasties, well after the commencement of our era, that the practice arose of covering them with colored glazes.



INNER FACE OF CORNER OF CHINESE CITY WALL WITH RAMP FOR ASCENT. EXTERIOR FACED WITH BRICK.

CROSS SECTION OF CITY WALL OF PEKING, SHOWING CONSTRUCTION; FACED BOTH EXTERIOR AND INTERIOR WITH BRICK.

PORTION OF GREAT WALL OF CHINA, NORTHWEST OF PEKING, BUILT OF EARTH WITH EARTHEN TOWERS.

PORTION OF EASTERN WALL AND MOAT, PEKING; TO SHOW "BASTIONS" CORNER TOWER IN DISTANCE.

THE NATURAL LIMITS TO HUMAN FLIGHT [1]

By H. E. Wimperis, C. B., C. B. E., D. Eng., F. R. Ae. S.

[With one plate]

INTRODUCTORY

The more I think about the subject chosen for this address, the rasher does it seem. To proclaim limits to human flight is to do two things. To say what can be done, and to suggest what cannot. Now, though there may be little rashness in the one, there is much in the other. If I say that such and such a thing can be done and someone in the distant years points out that actually it has not been done, my shade has the easy reply that achievement requires effort and that my critics should use their brains. But if I suggest that certain boundaries cannot be crossed, what fun for the coming race of engineers who cross them (if they do), than to poke fun at the memory of your lecturer to-night! [2]

It must be rash since wise men have diligently avoided such issues. Can one think of any engineer who has endeavored to lay down for all time, what is the height of the highest skyscraper than can be built, or the longest bridge there can ever be thrown across a river, or the fastest motor car that the world will see? Again, does any ship builder dare specify a natural limit to the size of future ships or to the power of the engines they will carry?

Why in the field of aeronautics is this rashness found? It must, I submit, either be because the subject is so well knit to its scientific foundations that prophecy is tempting, or else, I tremble to say it, that the impetuous youthfulness of aeronautics blows caution to the winds. But if impetuosity be the key to the answer, I urge that by assembling this row of aeronautical ninepins, I encourage the resourcefulness of coming generations by providing them with the zest of knocking them down. And that, I think, is worth doing.

The globe on which we live is a nearly spherical ball 8,000 miles across. Its highest mountain, like its deepest sea, is about 5 miles

[1] Presidential address delivered before The Royal Aeronautical Society on Monday, April 26, 1937. Reprinted by permission from The Journal of the Royal Aeronautical Society, vol. 41, No. 324, December 1937.

[2] And when I use the word "flight," I mean flying with wings and not the flight of a projectile.

114728—39——38

from the surface. Let us make a model. We take in our hands an 8-inch globe to represent the earth and show on it all mountains and all seas. The noblest mountain will project but one two-hundredths of an inch, and the greatest sea be a depression of no more. In handling such a globe, it would be difficult even to feel the roughness of the mountains or to detect the dampness of the ocean. Still more surprising is it, that if the Bristol airplane were actually flying through the atmosphere at the ceiling of its record-breaking height, it would only just be possible to squeeze under it a sheet of ordinary writing paper!

This shows the scale of things in true proportion. We are confined

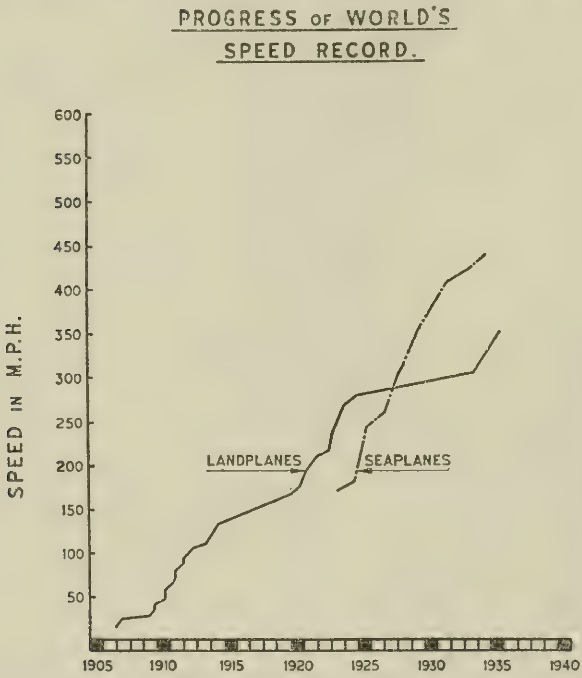


FIGURE 1.

to a very thin shell in which to move and have our being and this is the first of nature's bounds to the limits of human flight. If ever we are to hatch out from our shell, we must discover some lifting power which does not require an atmosphere.

It is easy to forget that our present attainments in human flight have all grown from the endeavors of a single generation. Our immediate predecessors in the air followed a much more leisurely course. Prof. Julian Huxley [3] writes of bird evolution:

One thing at least is certain and significant; whereas in the general stock of mammals, progress was being made and new and specialized lines budded out

[3] Bird watching and bird behavior.

up till a mere 5 or 10 million years ago, the birds settled down to stability about half-way through the Teritiary Epoch, about 20 or 30 millions of years back, and since then, though they have doubtless sprouted out innumerable tiny side-twigs of new species and genera, do not seem to have made any real evolutionary progress.

Nor, he adds, are they in the least likely to achieve any in the future since they appear to have reached the limit of perfection attainable in the circumstances prevailing upon the earth, by the kind of creature which they are. Mankind has certainly speeded up the previous rate of aeronautical evolution.

HIGH SPEED

I think I cannot do better than approach the problem of the attainment of high speed than by quoting from the Creevey papers. The adventure related, took place just over 100 years ago.

> To-day we had a lark of a very high order. Lady Wilton sent over yesterday from Knowsley to say that the locomotive machine was to be upon the railway at such a place at 12 o'clock for the Knowsley party to ride in if they liked, and inviting this house to be of the party. So of course we were at our post in three carriages and some horsemen at the hour appointed. I had the satisfaction, for I can't call it pleasure, of taking a trip of 5 miles in it, which we did in just a quarter of an hour. * * * The machine was occasionally made to put itself out or go it; and then we went at the rate of 23 miles an hour. * * * But the quickest motion is to me frightful: it is really flying, and it is impossible to divest yourself of the notion of instant death to all upon the least accident happening. * * * Altogether I am extremely glad indeed to have seen this miracle, and to have travelled in it. Had I thought worse of it than I do, I should have had the curiosity to try it; but having done so, I am quite satisfied with my first achievement being my last.

Perhaps it was his last but others were more adventurous. Around the attainment of high speed, immense human interest has always centered. The breaking of such records now rank as international events, and the world probably spent a million pounds over the last Schneider Trophy race. It is estimated that the "record" has been rising steadily for 25 years at an average rate of 15 miles per hour annually. Where is this to stop? Must it stop?

The attainment of very high speed depends upon combining great engine power with low airplane drag. It is less obvious how it will depend upon the altitude of flight. The latter question, however, is very important, and perhaps we may consider it first. As we increase height we decrease air density, and therefore decrease drag, so that flying at altitude, if speed is desired, seems good sense; but this simple conclusion is complicated by the engine factor and several others. Let me deal first with the engine. The engine power is as much affected by change of air density as is the drag, and how do these conflicting tendencies balance the one against the other? This

is, I think, most easily seen by drawing a single curve showing for a representative design the amount of engine power necessary at all heights in order to produce a specific level air speed. With such a curve sheet (kindly drawn for me by Mr. A. R. Collins) it is simple to add a graph showing the power which would be given at each height by the engine; then when the engine is shown by the curve sheet to

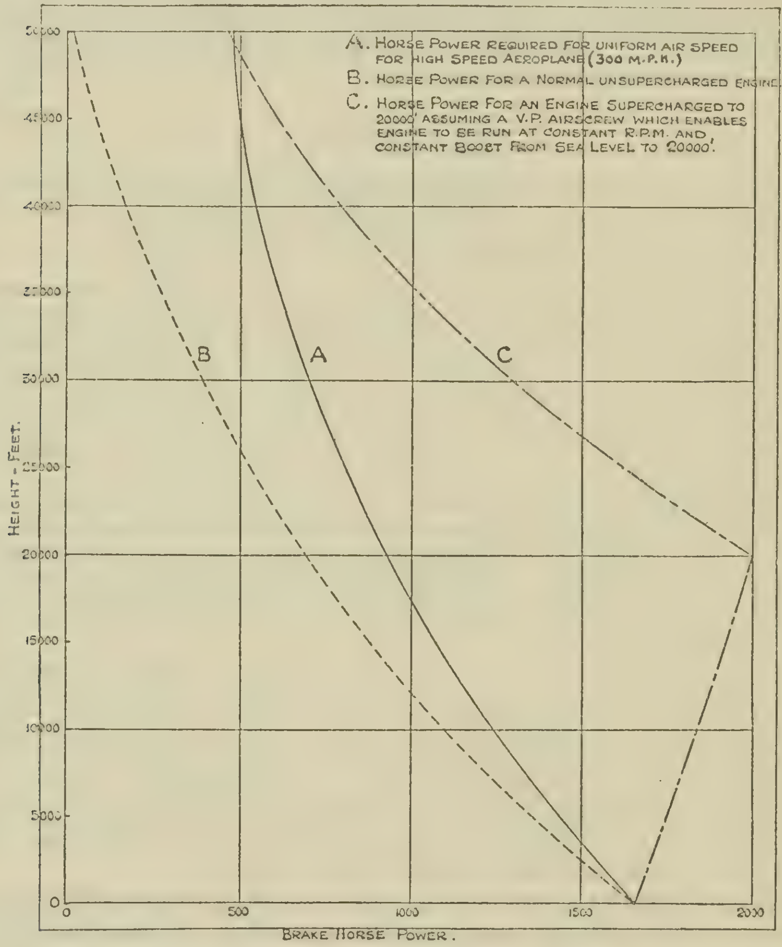


FIGURE 2.—Power against altitude for constant speed.

be giving more power than is required for the basic speed chosen, it is clear that a higher speed is attainable. A glance at this illustrative diagram shows that this increase of speed is at its maximum at the rated height of the engine (i. e., the height at which the supercharger just maintains the power at its sea-level value), and that afterward the surplus power, and therefore the additional speed, will fall off till the two curves cross, which they do at the altitude at which the speed

is again at its original value. This diagram shows in a simple way that merely pushing up the height of flight without paying attention to the way in which the engine is affected by that height would be foolish. Merely pushing up the altitude will not give greater speed.

Moreover, increase of altitude brings in other effects which we must not ignore. One is that when flying near the ceiling, the angle of incidence is increased, and with that increase comes a growth in the relative proportion of induced drag to parasitic drag; this formerly quite small fraction now becomes too large to be ignored and its effect is to bring down the speed attained. Further, there has to be considered the effect of change in Reynolds number with height of flight.

The Reynolds number is too well known to need description, but it is less well known that change in that number as an airplane climbs to a height has an important and adverse bearing on the drag coefficient. For a given wing, wing loading, and angle incidence, the dynamic pressure ($\frac{1}{2}\rho V^2$) is the same at any altitude. But since Reynolds number is proportional to both density and air speed (ignoring for the moment any change in the viscosity of the air which affects but does not change the conclusion), it follows that the Reynolds number must fall as the air speed rises; hence the Reynolds number at a high altitude of flight, despite the higher speed, will be lower than at a less altitude.[4] Any lowering of the Reynolds number means an increase in the drag coefficient for both laminar and turbulent skin friction. Hence for flight at altitude one must allow a higher drag coefficient than would correspond to sea-level conditions. This is a factor adverse to attaining great speed at height.

Apart from these particulars, the question of getting the highest possible speed is one of providing an airplane which, while comfortably containing pilot and engine, will have the minimum amount of "wetted" area in proportion to engine power. Obviously, the body, must be such as to house the pilot comfortably; this provides a certain cubic capacity for the engine space in front of him, which in turn governs the amount of power that can be derived from the engine. Would one get any more speed by building a more spacious airplane? Since a 10 percent increase in dimensions would put up the engine power possibilities by 30 percent and the wetted area by only 20 percent, it is clear that one could, although with the disadvantage of an increased landing speed. For any size of airplane, however, the amount of power available related to the drag coefficient which corresponds to turbulent skin friction, gives a definite limit to the speed attainable unless some method of getting still more engine power from that given space, or of reducing (if we know how to) some part of the drag to the lower level which corresponds to laminar flow. As Relf

[4] Cf. Von Karman on The problem of resistance in compressible fluids, Rome, 1936.

pointed out in his 1936 James Forrest lecture, to make the flow remain laminar over the whole surface would be to reduce the drag to one-tenth of the values now normal. This I do not think we shall ever attain, but whether we do or not, we can at least ensure that wing surfaces shall be made exceedingly smooth, particularly near the leading edge and very particularly on the upper surface of the wing; and we can see that when flush riveting cannot be used, the shape, and place, of the rivets is such that they do not project through the laminar layer. Steps can also be taken, now that the technique is known, to reduce greatly the engine cooling drag—even if it may be to convert it most marvelously into a small thrust.

Action on these lines applied to the designs of today soon brings one close to the most formidable of all nature's fences; that is the natural limit to the speed with which the air is able to get out of the way of the advancing airplane. The speed at which air can move when pushed is the same as the velocity of sound, and once the airplane speed approaches this boundary, it becomes more and more difficult to push away the air in front. And there is nothing we can do to increase the velocity of sound.

Perhaps we should study the mechanism more closely. When a body moves it compresses the air just in front of it, and the resulting pressure is communicated to the air farther ahead. This communication is, as I have said, carried out at the velocity of sound in the medium. In air of normal sea-level pressure and temperature, this velocity is 750 miles per hour. At greater altitudes it is less, not because the pressure is less, but because the temperature is. If the temperature were everywhere the same, the velocity of sound would not change. Actually the square of the velocity is directly proportional to the absolute temperature, so that in the stratosphere instead of being 750 miles per hour it is only 650 miles per hour.

What precisely happens when the speed reaches this limit? When that happens, the air ahead cannot be "warned" of what is coming. This leads to as many shocks and collisions as if an unlighted motor car tried to get through a crowd of deaf people on a dark night. When an airplane moves as fast as, or faster than, the velocity of sound, collisions with the air particles are inevitable and there will be an enormous loss of energy, through conversion into heat in the resulting shock waves. Hence, the drag coefficient rises to a high value as the velocity of sound is reached, and although it subsequently recovers somewhat, it still remains very much higher than the subsonic figure. Moreover, every roughness point on the airplane produces its own shock wave and therefore its own particular loss of energy. It is true that the lift coefficient also increases at this time, but the ratio of the lift to drag is substantially reduced and a less efficient airplane results. To some extent this might be thought to

be overcome by a change of wing section, but since the wing section cannot well be changed during flight, no compromised wing section can be the best both at subsonic and supersonic speeds.

The forms of aerofoil employed for the air speeds customary today have been studied unremittingly—even exhaustively. Much less is known of those suited to supersonic speeds though work on airscrews gives us some lead. But it seems that sharper leading edges will be needed and wings less deep than at present. Even so, the best lift to drag ratios may be nearer 5 than 20, and this, if it continues, will have striking consequences. Let us consider what could be the physical requirements of an airplane flying at a speed equal to the velocity of sound. An airplane weighing a ton will have a drag of one-fifth of a ton on wing drag only, and perhaps as much as one-third of a ton over all. This for a speed equal to the velocity of sound will require 1,500 horse-power per ton—and, as this is the net figure, the gross may be roughly put at 2,000. But a present-day engine of this size would require the whole of this weight allowance and there would be none left for the airframe and its contents! If speeds such as these are to be attained it cannot therefore be by the engine as we know it today.

In point of fact the limit to speed is reached even more rapidly than these considerations indicate, since the air speed just above the top of the wing is appreciably higher than the air speed of the machine itself. Hence the critical boundary will be reached while the air speed of the airplane is still substantially below the velocity of sound. Taking everything into consideration, there is much to be said for assessing the maximum possible speed of level flight with the present type of engine as over 500 but less than 600 miles per hour. It is true, however, that if we could suppress everything but laminar drag, or if there were some entirely new prime mover invented giving vastly greater thrust than an internal combustion engine of the same cubic capacity (even one using the very latest fuels of the highest octane numbers), it might be still possible to force the airplane through the air at even higher speeds. But there is not the least present indication of either of these being practically possible. So 600 miles per hour is likely to remain the limit to the speed of human flight.

The highest speeds today are all sea-level speeds, but the greatest speeds in the near future are likely to be attained at high altitudes, though as they will be the achievement of military types we shall not hear much about them; a few years later they will again be attained at sea level—since at sea level the velocity of sound barrier is not so soon encountered. At sea level, therefore, it is that human flight will reach the limit imposed by nature's unclimbable fence.

THE POWER OF MANEUVER

In many forms of aircraft, power of maneuver is vital. Does the increasing speed of flight have any effect on this vital requirement whether because of a limit to the endurance of the human body or of the airplane itself? It is also important to know whether we are approaching some physiological limit to either the rate of climb or the vertical speed of dive. We are all more or less familiar with what is known as caisson disease. This trouble arises when a diver working under several atmospheres of pressure, with much nitrogen absorbed into his blood, comes to the surface and the surplus gas bubbles out as the pressure is relieved. During the climb of an airplane, the atmospheric pressure is also gradually relieved, but here the rate of change of pressure is so slight, and the total change of pressure so small, that the physiological effect is unimportant. Since, however, the rate of dive is vastly greater than any possible rate of ascent, it is reasonable to ask whether in this more rapid action physiological difficulties may not occur. Here an arithmetical parallel is of service. Even if we take a direct dive through 8,000 feet at as high a speed as 400 miles per hour, the total change of pressure is no more than any swimmer would encounter who dived 10 feet deep into water; moreover, the total time taken by the air dive, some 7 or 8 seconds, does not represent anything more sudden than would be encountered by such a swimmer. We may, therefore, conclude that there is little to fear in this case also. As Wing Commander G. S. Marshall, of the Royal Air Force Medical Service, put it in his lecture [5] to the Society: "Power dives are done at the almost unbelievable speed of 30,000 ft. per minute without apparent harmful biophysical effect." As regards acceleration in taking off, or deceleration in landing, these are not anything to which the human frame does not easily adapt itself. This applies also to the catapulted take-off. The acceleration to which we are all subjected in a motor car driven in normal London traffic is just as severe.

There are, nevertheless, other accelerations which arise during flight which are of a totally different character. These are the ones due to centrifugal force. An airplane steadily banked on a turn at 45° will impose a horizontal force on its occupants equal to their own weight and this combines with the normal weight of the body so that the total weight on the passenger's seat is increased by almost half as much again. Banking at 60° would double this load.

There are also large centrifugal forces introduced when an aircraft is suddenly pulled out of a dive. In almost any aircraft the controls are so powerful that it is mechanically possible for the pilot so to manipulate the elevator as to break a wing. Of course, for this to happen the acceleration imposed has to be exceedingly great, equivalent, perhaps,

[5] Royal Aeronautical Society, January 1933.

to 12 times the gravitational acceleration, commonly known as 12 g. It fortunately happens, however, that the human body shows warning signs of distress long before the airplane. When, for instance, an acceleration force of 5 g. is encountered, the body is affected in the same way as it would be were the blood suddenly increased to five times its normal specific gravity. The effect, naturally, is that the blood seeks a lower level, and by denuding the brain of its normal share, causes the failure of visual faculties known as "blacking out." This produces no permanent effect, but for the time being the pilot sees nothing, and even though he still maintains control of the machine, it is a control unguided by any visual information from either the instrument board or the external world. Even higher accelerations than this have been endured by pilots, though not with any degree of happiness. I have read of an American experience of 11 g. requiring subsequent hospital treatment, and of 15 g. leading to a complete crash, though in the latter case it was difficult to distinguish between the results of human failure and the failure of the airplane structure. Nature does then impose a definite limit to the safe rate of pulling out from a dive and that limit is a physiological one and difficult to modify by human ingenuity. One alternative is to await the long process of normal human evolution and another to induce pilots to adopt the prone position when flying—the one change might take as long to bring about as the other.

It will be natural to ask what happens to the human frame when the acceleration comes in the opposite direction, that is toward one's head instead of toward one's feet. This is what happens in the maneuver known as "the bunt," and there then arises a suffusion of the brain by more than its normal supply of blood, leading to what is known as the "redding out" of vision. This maneuver is, however, always a dangerous one and on it authority frowns.

We have lastly to consider what I mentioned first, the effect on maneuver of the steadily rising air speeds of modern aircraft. The relationship is a simple one. The measure of the acceleration which has so marked a physiological effect is proportional to the product of the angular rate of turn by the linear velocity. If, therefore, the linear velocity be doubled, as has indeed happened over a comparatively short range of years in typical aircraft, the rate of maneuver must be halved if the safe acceleration limit is not to be passed. It follows from this that as machines become more and more speedy, so they must become less and less maneuverable. The effect of this on the dog fighting of the past is outside the scope of this address, though it is an interesting subject on which to speculate.

Let the speeds of aircraft increase as they may, the speed of nerve impulses in the human pilot will remain unchanged, namely, about 100 meters per second. Moreover, as in other means of signalling,

terminal delays need to be taken into account. It appears that when a nerve impulse starts from, say, the hand to reach the brain, the overall time taken for the response is very much longer than that of the mere passage of the signal along the nerves. This time lag before the brain is able to act on information received was, I feel sure, an important factor in some tests carried out a number of years ago at Farnborough. It was then thought that it would be a good thing if an indication could be given to the pilot when he pulled out from a dive, of the moment when he put on an acceleration higher than was safe. This indication was given by having inside the control lever a tiny accelerometer unit which, when the acceleration passed any set limit, say, 4 g., jerked the pilot's hand. The jerk warned him that it was advisable to slacken off the rate at which he was pulling out. The instrument worked well, but the idea failed because although the indication was given to the pilot's hand and thence to his brain, the airplane was too quick for the combination. Careful laboratory tests showed that it was impossible for the pilot to push the control lever forward in less than one-fifth of a second after the indication had been given by this device to his hand. In actual flight the time lag might be longer. In the words of the report[6] presented to the aeronautical research committee: "In the case of intentionally violent use of the controls no warning however swiftly given could be of service to the pilot."

Incidentally, anyone who wonders what an acceleration of 5 g. is like can obtain the information without getting into an airplane at all. Consider a child swinging in an ordinary garden swing. If the child swings up to such a height that he can just see the horizon over the top bar he will experience as he rushes past the bottom of the swing an acceleration force of 3 g. If the swing be of the fair type with iron rods in place of ropes we can in theory, at any rate, start the swing from the very top (so that the poor child is inverted and has to be strapped in). In this extreme case the acceleration force when the seat swings through its lowest position will be exactly 5 g.; and this it will always be whatever the height of the swing or the weight of the child.

The effect of applying to the human body a steady lateral acceleration can also be illustrated by an ingenious device at the University of Göttingen, where a cylindrical room is mounted on bearings so that it may be rapidly rotated. People standing in that room see nothing but a dial to tell them that the room is being rapidly turned round, but the effect upon their limbs when they try to use them, and still more on their mental sensations when they suddenly incline their head serves to show how easy it is to deceive the brain as to what

[6] R. & M. 1446.

is taking place. The relation of this to the spinning airplane is of interest.

THE EXTREME ALTITUDE OF FLIGHT

I come now to the problem of high flying. What are the conditions which limit the altitude of flight? We know that the higher one flies the lower the air density and the smaller, therefore, the quantity of oxygen that passes into the human lungs and into the engine cylinders. The engine itself is really almost human. It breathes in air, it takes in fuel, it changes it chemically, gets rid of waste products, maintains its own warmth and does not like being either too hot or too cold. Like the human body it is liable to suffocation and needs supercharging or the equivalent thereof. There are two effects to consider, the effect of oxygen want in the human body and of a similar lack in the airplane engine. It so happens that the effect on the former operates much more rapidly than it does on the latter. Both are accustomed to working under normal atmospheric conditions at sea level where the pressure is about 15 pounds per square inch, and the proportion of oxygen in the atmosphere about one-fifth of the whole.

We are fortunate in having a careful study of this question in a lecture delivered by Prof. G. T. R. Hill before the Royal Society of Arts in 1935. I think his conclusions are entirely correct—certainly on this point—and it is worth summarizing them. Since the air pressure at 35,000 feet is just one-fifth of what it is at sea level, it follows that human beings will be as well off with oxygen at that altitude as by breathing ordinary air at sea level. But experience has shown that even without any artificial supply of oxygen, flight at 15,000 feet is possible; the lungs can adapt themselves to that condition of slight oxygen starvation—provided that no particular bodily exertion is called for. Supplying pure oxygen at 42,000 feet would correspond to this same degree of starvation. But when 45,000 feet is reached oxygen starvation reaches the fainting point—a condition similar to that which arises in the absence of oxygen at some 20,000 feet. The supply of pure oxygen to the pilot, making the oxygen richness approximately five times as large as it would otherwise be, has, therefore, the effect of postponing the normal fainting point for the average pilot to some 45,000 feet, which corresponds very closely to the altitude records obtained in recent years when the pilot was fed in this way. Thus Uwins reached some 44,000 feet in 1932, and Donati 47,000 in 1934. The opinion expressed by Wing Commander G. S. Marshall [7] some 4 years ago was that while the safe limit of height for a person breathing pure oxygen was 44,000 feet on a flight straight up and down again, he would not state this to be the limit of possible human endurance. How high birds can fly I do not know, but Hugh Ruttledge

[7] Royal Aeronautical Society, January 1933.

showed in a recent lecture on an Himalaya climb a photograph of a lark sitting on her eggs at a height of 18,000 feet. And I suppose she did not get there on her feet!

The existing altitude record of 50,000 feet, obtained in 1936 by Flight Lieutenant Swain in a Bristol airplane, was reached in a different way. In this case the pilot was enclosed in a suit—rather like a diver's suit—which could be kept at a pressure of several pounds per square inch higher than that of the external atmosphere. Oxygen is preferred for such a suit because of the lower pressure required and hence the greater ease of movement. Actually 2½ pounds per square inch

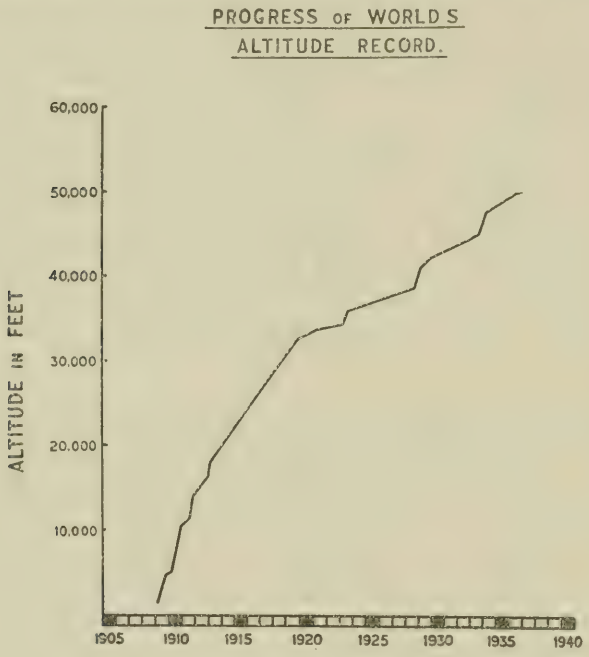


FIGURE 3.

is found to be a convenient pressure, and such a suit has been tested in a low pressure chamber to a "height" of 80,000 feet.

Of course, one may go further than a special suit and provide an enclosed cabin in which a suitable internal pressure is artificially maintained. Although there would be grave objections to this in a military aircraft, there would be none in civil machines other than perhaps a reluctance to face the necessarily cramped space in which the occupants would be confined. Although the temperature is low in the stratosphere, flight at high speeds brings its compensation, since any entering air would be heated by compression by the number of degrees centigrade that is equal to the square of the speed in hundreds of miles an hour, e. g., 9° centigrade at 300 miles per hour.

By these expedients it is possible, theoretically at any rate, to postpone indefinitely the failure of the human mechanism, and the limit to the altitude performance becomes solely that of the engine. Does nature here impose a definite limit? At 50,000 feet the air density is but a ninth of that at ground level, and since for practical reasons there is no question of supplying the engine with oxygen, the task of supercharging the cylinders adequately is a severe problem, beyond the capacity in fact of any single supercharger. Efforts to increase the altitude still higher than the present limit must impose more and more severe duties on the supercharging mechanism, which, therefore, must needs increase in bulk and weight. In the limit, this very increase in weight makes the attainment of higher altitudes more difficult. So far as present day possibilities in design are concerned, I may cite the estimate given by Mr. Barnwell in his lecture at Bristol in February last that if one went "all out" for an altitude record, a height of 61,000 feet should be attainable.

There must at any future time be a design limit to what is possible in the light of the materials then available, but it would be rash to forecast finality since the one thing which does seem limitless is the fertility of the brain of a designer once new materials become available. At present we have no means of predicting what new materials may arrive in the future. We are but beginning to grope our way through knowledge of crystal lattice structure towards a coming technique of alloy design.

THE RANGE OF FLIGHT

It is far from easy to find any limits imposed by the laws of nature on the greatest distance that an airplane can fly without refuelling. How, for instance, does range of flight depend on the size of the aircraft, the power of the engine, and the height chosen? It is sometimes thought strange that airplanes of what I may call the same vintage, using the same fuel and with equally efficient engines, show when flying at their most economical speed precisely the same figure of ton-miles per gallon (the figure is the same as that commonly obtained in the ordinary motor car). This is true whatever the size of the airplane may be, and whatever the altitude of flight. I suggest that the simplest way to understand this seemingly strange result is this. At all air densities there is one particular incidence for a given airplane which gives the maximum value of the ratio of lift to drag, and, therefore, the lowest value of the drag for that particular airplane. Hence, when flying level at this incidence, the lift being equal to the weight, the drag must have a constant value. (I ignore for the moment the effect of any change of weight due to fuel consumption.) Now, with a constant drag force the work done to cover a specific distance through the air must be a fixed and definite amount, inde-

pendent of the air density, and, therefore, of the altitude of flight. If the engine is equally efficient at all air densities, it follows that the work done by the engine must also be the same for any given distance through the air, whatever the altitude. Hence, the minimum ton-miles per gallon must be independent of the altitude. There is no advantage, therefore, under still air conditions, in flying high in order to beat the record for range of flight.

In practice, of course, one has to allow for the fact that the total weight will gradually diminish as the fuel is used up. And in normal flying one must also allow for the consideration that flight at a speed

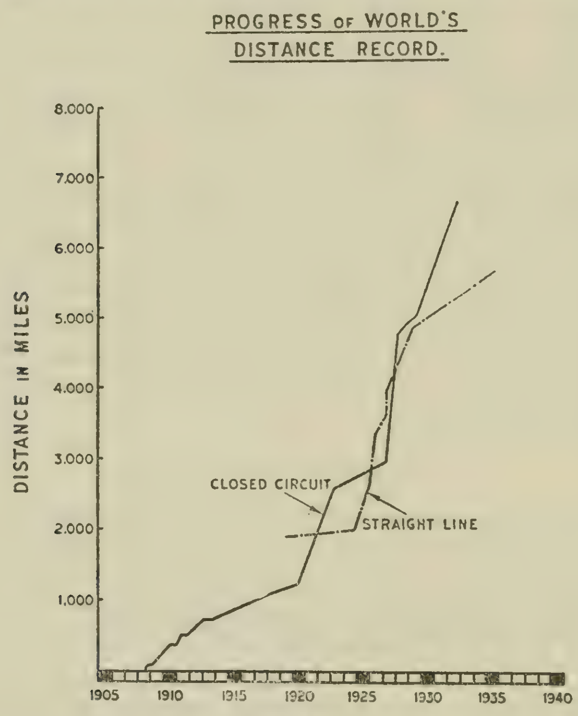


FIGURE 4.

which corresponds to the most efficient incidence may not always be operationally convenient, and that is what is found convenient cannot but be related to the speed of the prevailing wind, and since winds vary with altitude, the problem is complex.

Nevertheless, it is a convenient starting point to realize that for air planes having engines of a given efficiency using specific fuels, the maximum possible ton-miles per gallon tends to be independent of altitude. Hence, the natural limit to range of flight depends far less upon the altitude than upon the attainment of high engine economy, of low airplane drag, and of so low a structure weight as to allow really large fuel tanks to be carried.

Messrs. Rockefeller and Moore have recently published a forecast that a range of 20,000 km without refuelling may ultimately be attainable. If they are right, we shall attain a range enough to enable every single spot on the earth to be reached from every other—a conclusion which will please those who have neat minds, but alarm those who love solitude.

SOME REFLECTIONS

I think it would be fair to say of all of us that our reflections on this intense aeronautical activity are mixed; even confused. There is the view expressed by Lord Trenchard many years ago (Cambridge in 1925), that if he had his way he would "abolish the air." The same view was wittily expressed recently by a writer in "Truth"—"What a pity, though, that the Creator, when he made flight so difficult to achieve, did not do the job thoroughly and make it absolutely impossible!" But—"Unfortunately, as Adam and Eve learnt to their cost, it is easier to obtain knowledge than to escape from its consequences."

There is, however, another side to this great question. The fears expressed are largely those engendered by a form of warlike attack against which there is thought to be little or no defense. But the struggle between attack and defense has taken place in all ages, and with all forms of weapon; sometimes the pendulum swings in favor of the one and sometimes in favor of the other. With aircraft, the attack has for years been in the ascendant, the pendulum is even now over on that side; but this I am glad to think is a passing phase, and already the pendulum is on the move.

May I quote two striking sentences used by Colonel Lindbergh during a recent visit to Germany—"The responsibility which we incur by creating a powerful destructive force is lightened by the knowledge that this force is being controlled by reason and experience, and that we have separated such a force from ignorance. I find hope in the belief that power which goes hand in hand with knowledge will not be a menace to civilization."

As I suggested by way of comfort at one of our recent meetings, no country can become materially strong in the new Arm of the Air unless there exists in almost limitless degree noble gallantry in its young men, and fine intelligence in the engineers charged with the development and construction of this Arm. Changes now in sight will, I am certain, call in future years for these great qualities even more intensely. And though the qualities of gallantry and fine intelligence may perhaps not be the supreme human qualities, they are, nevertheless, most noble ones, and it is a happy thought that those countries alone which possess them can become great in the strength of the new Air Arm.

HOLDER OF ALTITUDE RECORD (BRISTOL 138).

THE HISTORIC AMERICAN MERCHANT MARINE SURVEY

By Frank A. Taylor
Curator, Division of Engineering, United States National Museum

[With 11 plates]

The progressive development of watercraft can be discussed intelligently only with accurate knowledge of the actual designs of hundreds of specialized types of craft. The lack of such knowledge has resulted in unsatisfactory generalizations about the designs of many vessels which have figured prominently in our history and overemphasis upon relatively unimportant but better described types. It is true that several authorities in the past have made compilations of designs of watercraft and in more recent times many plans of important individual vessels have appeared in textbooks and professional publications. But these are scant records of a large and involved development and they have been used almost to exhaustion by students and writers. Most of the inferences in regard to the development of watercraft have been drawn rightly or wrongly from these too meager sources.

Plans of early naval vessels are preserved in the archives of national admiralty offices and are reasonably available, but there are no comparable collections of plans of merchant vessels. In the United States about a half-dozen museums, libraries, and universities and an equal number of collectors and students have worth while collections. The bulk of these, however, relates to large merchant vessels of the period of 1840 to 1885 which were built at well-established yards where the models and plans from which they were built were fortunately preserved. Though much of the missing information has been irrecoverably lost, there is in existence a large quantity of invaluable evidence which requires to be sought out and preserved. It was to secure as much as possible of the passing evidence now available and to put it into form for preservation and distribution that the Historic American Merchant Marine Survey was created.

The scheme of the Survey as conceived by its originator and director, Eric J. Steinlein, was to establish a project of the Works Progress Administration to employ unemployed professional people and mechanics from the ship and boat building industries to make marine architectural drawings, photographs, and written reports describing old vessels. The records produced were to be preserved and made

114728—39——39

available for study in the Watercraft Collection of the United States National Museum. The sources of information for the records were in most instances old vessels still in existence and in other cases the authenticated models, plans, and tables of dimensions in collections not readily available for study. The distribution of the sources indicated a national set-up, and regional offices were established wherever the supervisory and operating personnel could be organized to function within the limited time originally determined upon as the life of the project. Regional offices were established at Portland, Maine: Boston; New York; Wilmington, Del.; Baltimore; Hampton, Va.; Jacksonville; Tampa; Chicago; and San Francisco. Though the life of the project was extended from time to time, it is unfortunate that no single extension was for a sufficient length of time to justify creating new regional offices other than those originally established. It is obvious that many localities where there have been important developments of watercraft were not reached by the Survey.

The actual operation of the Survey fell largely upon the regional supervisors, many of whom were authorities on the subject and were persuaded to undertake the work out of a spirit of public service, while others were selected upon the recommendations of museums, or students of watercraft in the localities. These men in turn selected their personnel from local unemployed pools and organized field survey parties and drafting offices. The supervisors, upon suggestions from the Director, made preliminary surveys of their localities and submitted reports upon vessels and material available for survey and in return received instructions as to the order in which the work should be undertaken. Priority in most cases was given to vessels or material in immediate danger of being lost or destroyed and to desirable vessels due to be hauled out for painting or repairs. The drawings, photographs, and reports were completed under the direction of the regional supervisors and sent to Washington with the original field notebooks for the approval of the Director and acceptance by the National Museum. The surveys accepted total 270 vessels, 677 drawings, and 545 photographs which, with field notes and reports, are readily available for examination and study at the Museum. Negatives of drawings and photographs are kept on file and prints of both are distributed upon order at nominal cost.

The file of well-executed drawings and supporting material produced by the Survey is beyond question one of the outstanding compilations of designs of American watercraft. Descriptions of a few surveys will indicate the scope and character of the work.

Typical of the surveys of local types are those of the scow schooners of San Francisco Bay. These vessels are descended from the first boats built in California after the gold rush and several, converted to power, are in use today in much the same trade as the first ones.

At one time more than 100 were in use carrying hay, grain, gravel, and bricks about the bay and tributary rivers. They appear to have been built by "rule of thumb" or the experience of one generation of builders passed on to the next, and no plans have been found. The last one was built in 1904, though one built as long ago as 1870 was made the subject of a survey. The drawings show shallow-draft, scow-ended, flat-bottomed vessels of simple construction, well suited for sailing in shoal waters and for beaching on an even keel for loading where there were no wharf facilities. They ranged in length from 60 to 90 feet, with 65 to 75 feet the most popular size. None of the vessels surveyed was rigged for sail, but original sail-makers' draughts supplied the details for the restoration of sail plans. The schooner rig with main gaff topsail was the most popular, though some were without topsails, some had fore and main gaff topsails, and a few were sloop-rigged. Early photographs show the scows carrying enormous deck loads of hay with the sails reefed high to clear the load and the helmsman steering from a pulpit built up 10 or 15 feet above the deck.

The same waters have produced many other distinctive types of craft of which the oddest is, perhaps, the felucca. It is a small lateen-rigged, double-ended, open boat formerly employed by the Italian fishermen of San Francisco Bay. Unlike any other American type, its sweeping, slanting spars were patterned on those of Mediterranean boats familiar to the Italians. Toward the end of the last century scores of these fished in the Bay, but only one could be found recently to survey for the purpose of preserving its design. An effect of the survey of this particular boat was to focus attention upon it as probably the last remaining one of its type with the happy result that it was subsequently acquired by the Mariners' Museum for preservation.

Other interesting local craft, large and small, too numerous to describe in detail, were surveyed and drawn up wherever the Survey operated. Great Lakes schooners and steamers of many periods, a collection of Mackinaw fishing boats, and a Wisconsin logging bateaux indicate the variety of some 60 surveys produced by the Chicago office.

In Florida, surveys were made of the greatest variety ranging from the sponge sloops of Greek influence to old sternwheel river steamers. These last are represented by two steamers built in 1870 and 1898, the wrecks of which still remain. They were important links in the transportation of travelers before the railroads ran along both coasts and across the State. They typify the period when the slowness and hardship of travel were compensated for by the leisure to observe the details of the country. The steamers, for example, were equipped with iron baskets to carry burning light wood to

illuminate the banks while young officers called "Alligator on the left," "Alligator on the right," or "Low trees!" for the entertainment and safety of the passengers on the cabin roof.

The survey personnel working from Hampton, Baltimore, and Wilmington turned in excellent surveys of the Chesapeake Bay and Delaware Bay types as well as of the large wooden ships built in great numbers in the yards about Wilmington. The surveys of Chesapeake Bay log canoes of many types from both ends of the Bay provide the first complete collection of data for a comprehensive study of this craft. A number of the drawings were reproduced even before the completion of the Survey in Chesapeake Bay Log Canoes, in 2 volumes, by M. V. Brewington (Mariners' Museum, Newport News, Va., 1937).

The New York office served principally as a draughting office and did good work in finishing drawings from data fed to it by other offices not so well staffed with draughtsmen. An outstanding original contribution was made in the drawings of the lines of the famous clipper ship *Sea Witch*, designed by John W. Griffiths in 1846. It is the first time that these lines made from an original drawing in the possession of the granddaughter of Griffiths have been available for study.

New England, as might be expected, was a fertile field where the problem was not to find subjects to survey but to select the most useful evidence to preserve. Two different undertakings there will indicate the scope and caliber of the work. Permission was obtained to secure the lines of half models in a little-known and not readily accessible private collection representing the vessels operated by one family firm during the larger part of the nineteenth century. This collection includes half models of vessels built from 1849 to 1872, represents the work of some 26 different builders, and illustrates the development of the American merchant ship by some of the finest examples of marine architecture of the period. The period was one of the most active and interesting of American merchant marine history and the collection represents vessels of the preclipper or packet types, clippers, and modified clippers, and the later so-called down-easters.

Contrasted with this was the survey of the Piscataqua River gundalow, descendant of colonial hay barges and distantly related to the river and lake gun-boats of the Revolutionary War. Alluded to as early as 1650, scowlike vessels propelled by poles were used in the bays and rivers of New England to transport salt, lumber, marsh grass, etc. In the Piscataqua region these barges developed into fully decked, spoon-bow vessels, with lateen sails and leeboards. Of exceedingly shoal draft to go into the shallowest tributaries, they could carry more than 30 tons of cargo, and in the strong tideways of

the river were, reputedly, the match of yachts built for speed alone. They were propelled by a small sail bent to a slanting yard suspended from a chain on a stump mast so rigged and balanced that the yard and sail could be brought down almost to the deck to pass under bridges and raised again with the least possible inconvenience.[1]

In addition to the file of material described, the Survey had an inestimable value in the preservation of the skill and interest of craftsmen of the shipbuilding industry, as well as a record of some achievement in instructing young men and partially skilled personnel in more advanced branches of their work. Many men were called from employment on the Survey to old or new positions in the industry.

The Survey was terminated as a Federal project in October of 1937, though several offices have been continued as State projects under local sponsorship. Copies of drawings and other material produced by these projects are being currently offered to the National Museum for preservation with the main collection.

APPENDIX

A partial list of types and dates grouped under the Survey offices is as follows:

PORTLAND, MAINE.—Bay and river steamers, 1900–1907; schooners, 1873–1891; ship *Mount Washington*, 1840.

BOSTON, MASS.—Fishing schooners, 1856–1936; coasting and other schooners, 1854–1888; ships and barks, 1846–1873; Tancook whaler, 1909; Whitehall boat, 1860; No Mans Land boat, 1898; U. S. Revenue schooner, 1833; North River sloop, 1836; Friendship sloop, 1902; waterboat, 1866; sloops, 1876–1896; sharpies, 1900; gundalows, 1886–1936.

NEW YORK, N. Y.—Ship *Sea Witch*, 1846; Hell Gate pilot boat, 1886.

WILMINGTON, DEL.—Coasting and trading schooners, 1874–1877; bark *Sarah S. Ridgeway*, 1877; oyster schooners, 1904–1926; clam and oyster garveys: sturgeon and pot fishing skiffs; steamer *John G. Christopher*, 1892.

BALTIMORE, MD., and HAMPTON, VA.—Log canoes, 1835–1898; bugeyes, 1885–1902; sloops, skipjacks, 1852–1899; schooners, 1856–1899; fishing bateaux, 1920–1928; scow sloop, 1874; tow-boat, 1883; sail plans of Bay craft, 1862–1901; sloop *Frances* and pilot schooner *Mary Taylor*, 1849; Staten Island oyster skiff.

JACKSONVILLE and TAMPA, FLA.—Sponge fishing sloops, yawls, dinghies, from lateen-rigged *Hydra* to 1937; Bahama and keys fishing sloops, 1855–1930; schooners, 1855–1902; sharpies, 1884–1904; skipjack, c. 1875–1896; Seminole dugout, 1837; Nicaraguan cayuca; catboat, 1885; steam tugs, 1883–1895; river steamers, 1870–1898; the Danish bark *Prins Valdemar*, 1892; Long Island Sound sand-bagger sloop, 1872.

CHICAGO, ILL.—Lakes schooners, 1853–1895; steamers, 1852–1890; steam towboats, 1886–1896; steam barges and scows, 1873–1892; canal boat, 1875; river scow; scow schooner; sail plans of schooners, 1853–1881; Mackinaw fishing boats, 1887–1900; logging bateau, c. 1890; motor passenger boat *Gypsy*, 1911.

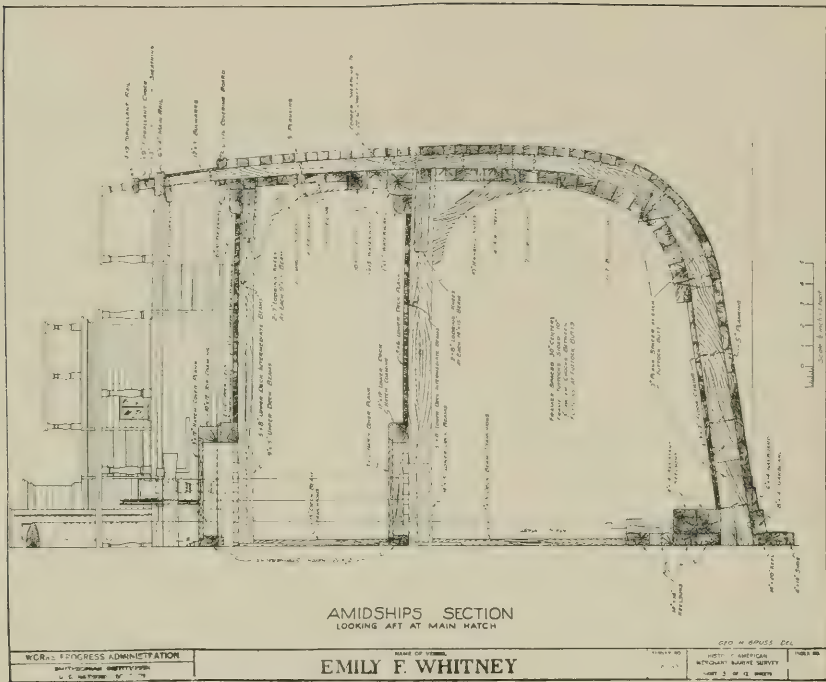
SAN FRANCISCO, CALIF.—Scow schooners, 1870–1902; ships, barks, and barkentines, 1880–1902; felucca, c. 1900; schooners, 1882–1917; Norwegian cutter *Gjoa*, 1872; steam schooner, *Roosevelt*, 1905; Diesel tugs, 1914–1923; paddle steamers, 1875–1894.

---

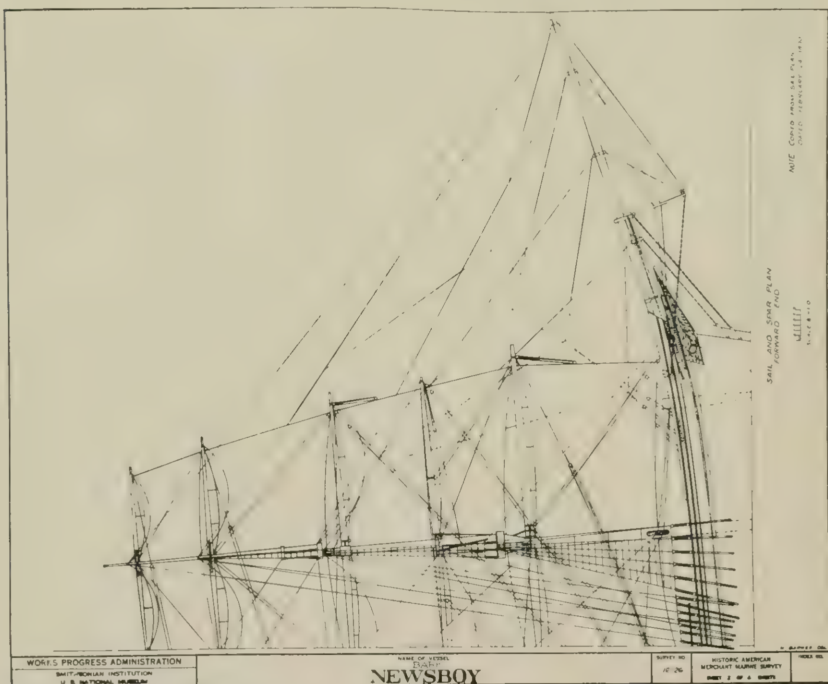
[1] A partial list of types of vessels surveyed with their dates is appended.

114728—39——40

CORNER OF BOAT HALL, UNITED STATES NATIONAL MUSEUM, 1937.

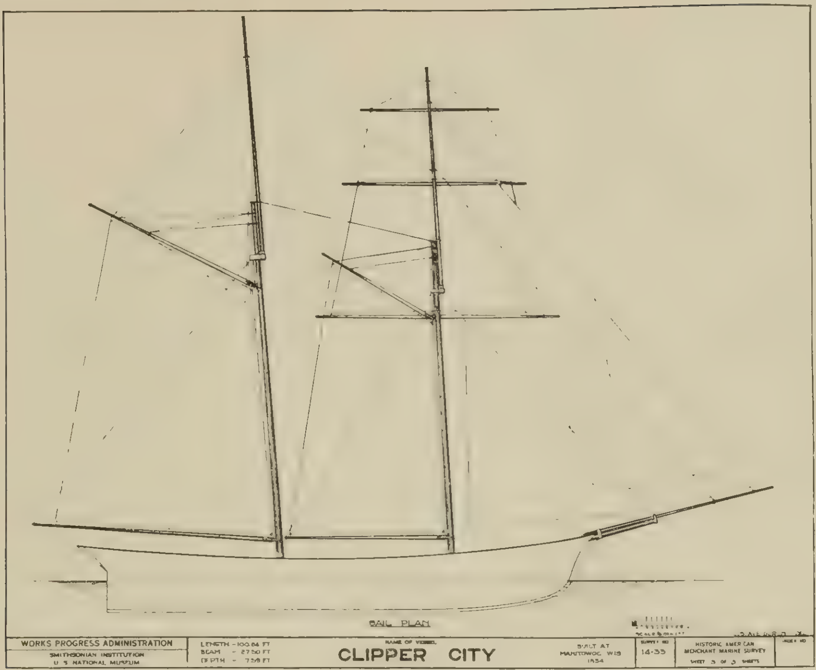


1. Bark *Emily F. Whitney*, 1880. Amidships section.

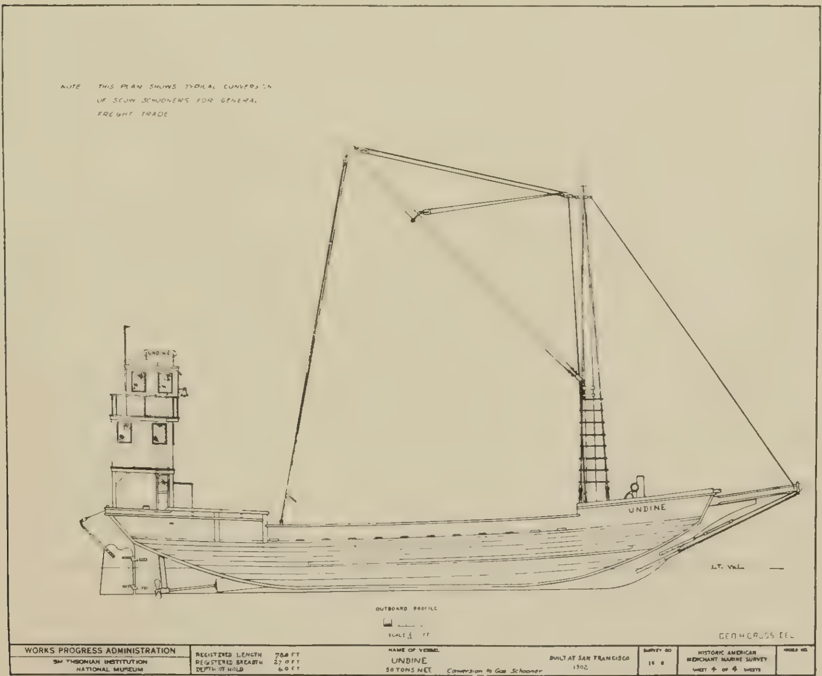


2. Bark *Newsboy*, 1882. Sail and spar plan forward end.

SPECIMEN DRAWINGS PRODUCED BY THE HISTORIC AMERICAN MERCHANT MARINE SURVEY. (ACTUAL SIZE OF EACH 17″ X 23″.)



1. Schooner *Clipper City*, 1854. Sail plan.



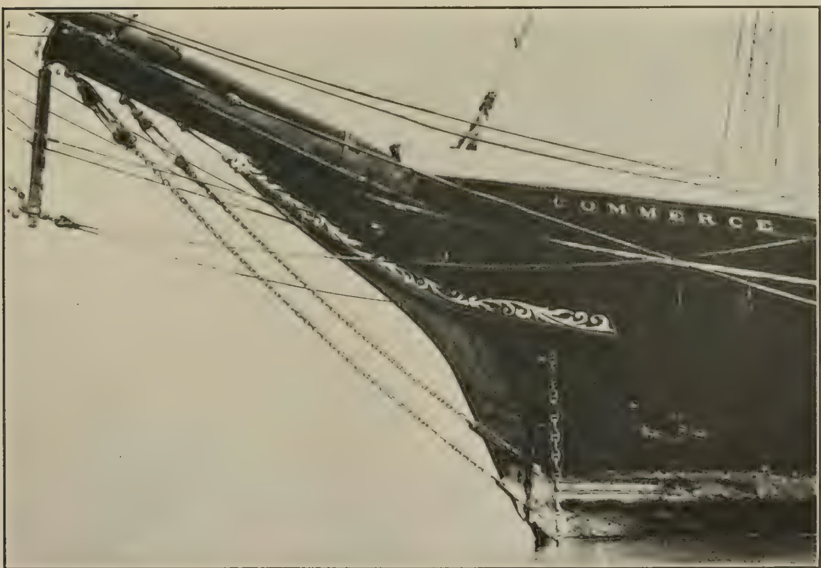
2. Scow schooner *Undine*, 1902. Outboard profile.

SPECIMEN DRAWINGS PRODUCED BY THE HISTORIC AMERICAN MERCHANT MARINE SURVEY. (ACTUAL SIZE OF EACH 17″ X 23″.)

1. Survey field workers aboard scow schooner at San Francisco.

2. Survey draftsman taking measurements of half model at Wilmington, Del.

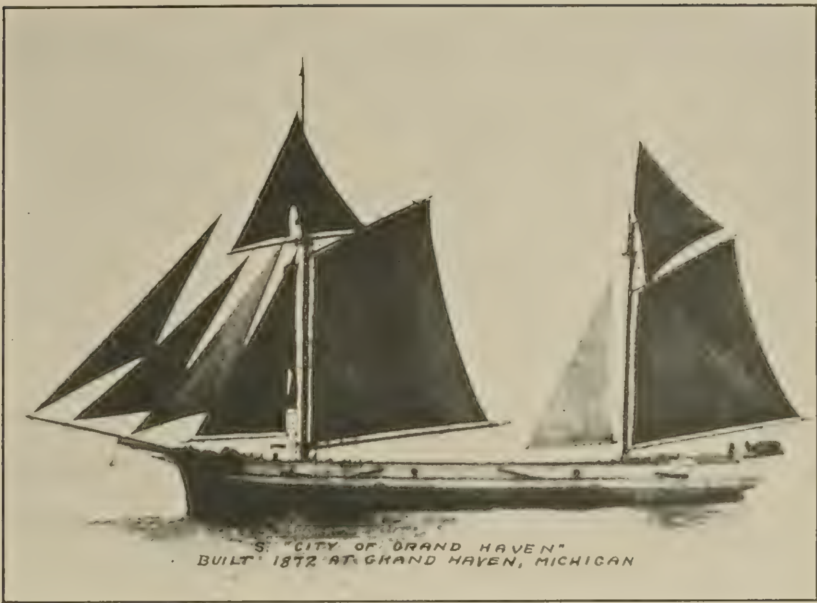
1. San Francisco Bay felucca. Old photograph made in 1889. (From Bureau of Fisheries.)



2. Head detail of four-masted schooner *Commerce* built at San Francisco in 1890.

1. Illinois and Michigan canal barge *City of Pekin*, 1875. Old photograph.

2. Lakes steamer *Sidney O. Neff*, 1890. Originally a tow barge.



1. Lakes schooner *City of Grand Haven*, 1872.

2. Wisconsin logging bateau, about 1890. (Courtesy American Legion Logging Museum, Rhinelander, Wis.)

1. Florida sponge dinghy or hook boat, 1923.

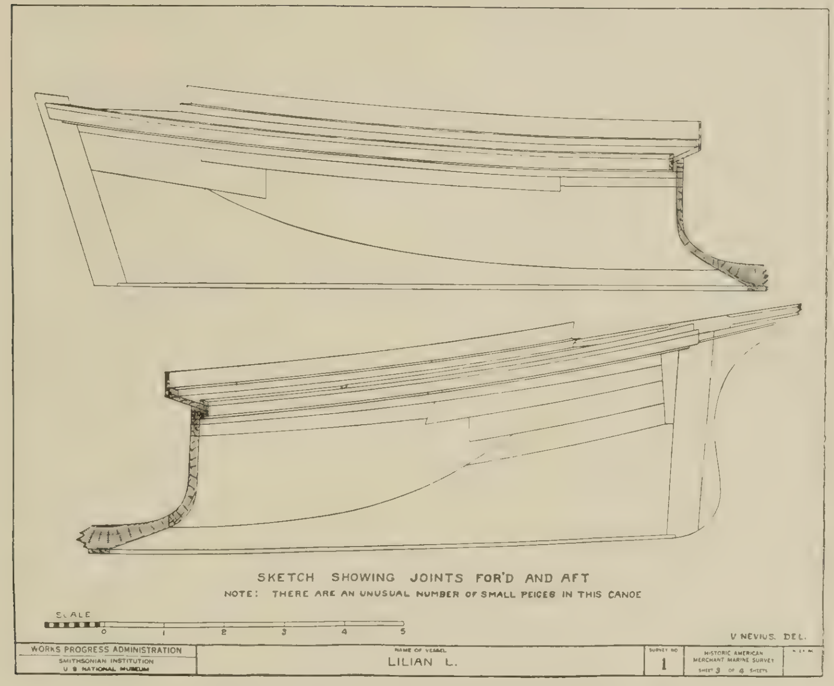
2. Staysail schooner *Virginia* built at Fish River, Mobile, Ala., 1865.

1. Oklawaha River (Florida) steamer *Okahumkee* built 1870. Abandoned on the river bank.

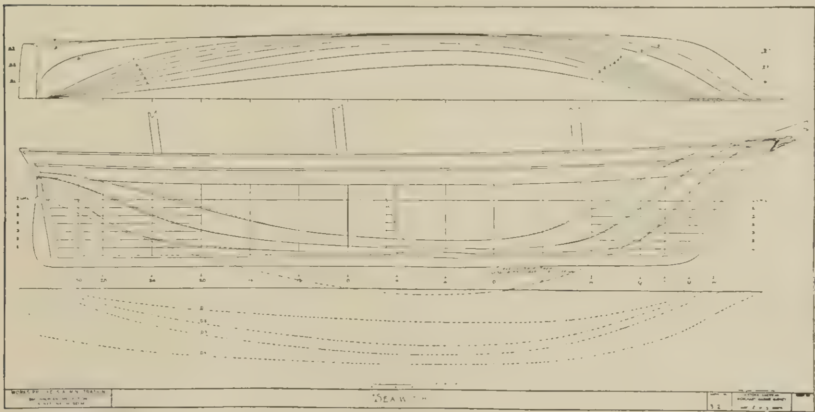
2. Chesapeake Bay bug-eye *Edith F. Todd*, 1902.

1. Oyster sharpies hauled out at New Haven, 1891.

2. Hulk of the last Piscataqua River gundalow, the *Fanny M*, built in 1886. (Photograph made by Prof. A. V. de Forest, 1925.)



1. Details of logs and joints of Chesapeake log canoe of about 1898.



2. Lines of the clipper ship *Sea Witch* built 1846.

SPECIMEN DRAWINGS PRODUCED BY THE HISTORIC AMERICAN MERCHANT MARINE SURVEY.

(Actual size of drawings, top 17″ x 23″, bottom 17″ x 36″.)

INDEX

A

B

C

D

E